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DESIGN AND DEVELOPMENT OF A 30MM ALUMINUM CARTRIDGE CASE

AMRON, DIVISION OF
GULF & WESTERN INDUSTRIES, INC.

TECHNICAL REPORT AFATL-TR-70-90

AUGUST 1970

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67

Design and Development

of a

30mm Aluminum Cartridge Case

Otto H. von Lossnitzer

FOREWORD

This effort was accomplished by Amron, Division of Gulf and Western Industries, Inc., Waukesha, Wisconsin, under Contract F08635-69-C-0222, with the Air Force Armament Laboratory. The Project Monitor for the Armament Laboratory was Mr. David G. Uhrig (DLDG). The period covered by the report was from 18 July 1969 to 17 July 1970.

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This technical report has been reviewed and is approved.

Charles Petrides
CHARLES PETRIDES
Acting Chief, Adv. Development Div.

ABSTRACT

This report describes the design, development, and testing of a 30mm aluminum cartridge case for the Air Force 30mm AX gun system. The program proves that a 30mm cartridge case is feasible and can be manufactured using the Aluminum Company of America X7475 material. Also, the Amron-designed cartridge case can be satisfactorily fired to the parameters set forth in the contract covering this program. This effort consists of an in-depth study of surface finishes that can be economically applied to aluminum. This report also describes the successful application of the XM-115 percussion primer (FA X10542585) developed by the U. S. Army at Frankford Arsenal.

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SECTION I

CASE DESIGN

GENERAL

The dimensional characteristics of the 30mm aluminum cartridge case were determined by establishing:

1. Gun design parameters in sufficient detail to permit a logical case design.

2. Case feasibility through selection of case material, propellant, and primer and an analysis of the static stress conditions.

The selection of the aluminum alloy, in close coordination with Alcoa Research Laboratories, provided a material which is not prone to splits or ruptures of the case body. The possibility of primer leaks and primer setbacks was considered.

Amron has developed a technique to form the primer pocket, which had proven in other case designs that leaks and setbacks can be eliminated.

The case design is strong enough to withstand pressures of 65,000 to 70,000 psi. The initial investigation of suitable propellants for the round resulted in this pressure figure being necessary to obtain the required muzzle velocity, based on the specified 5000-grain projectile weight. Static stress calculations of case wall and bottom support the design feasibility.

Aluminum offers important and desirable weight-saving advantages for 30mm cartridges. (See Figure 1).

GUN DESIGN PARAMETERS REQUIRED FOR CASE DESIGN

An aluminum cartridge case, like a case design in any other material, requires certain restrictions in the dimensioning of barrel, chamber, and bolt components of a weapon.

During the combustion of the propellant, the cartridge case grows in diameter until it fills completely the space between chamber wall and cartridge case outer diameter. The continuing pressure makes the barrel grow diametrically within its elastic limit. The case continues to grow with the barrel and is limited by the latter's expansion.

The wall thickness of the barrel material in the chamber area has to be carefully predetermined in order to eliminate undesirable overexpansion of the aluminum under pressure. For this reason, preliminary maximum and minimum chamber diameters have been determined as a restrictive guideline for the gun designer.

The longitudinal case expansion follows the same trend. In this case, preliminary maximum and minimum dimensions of

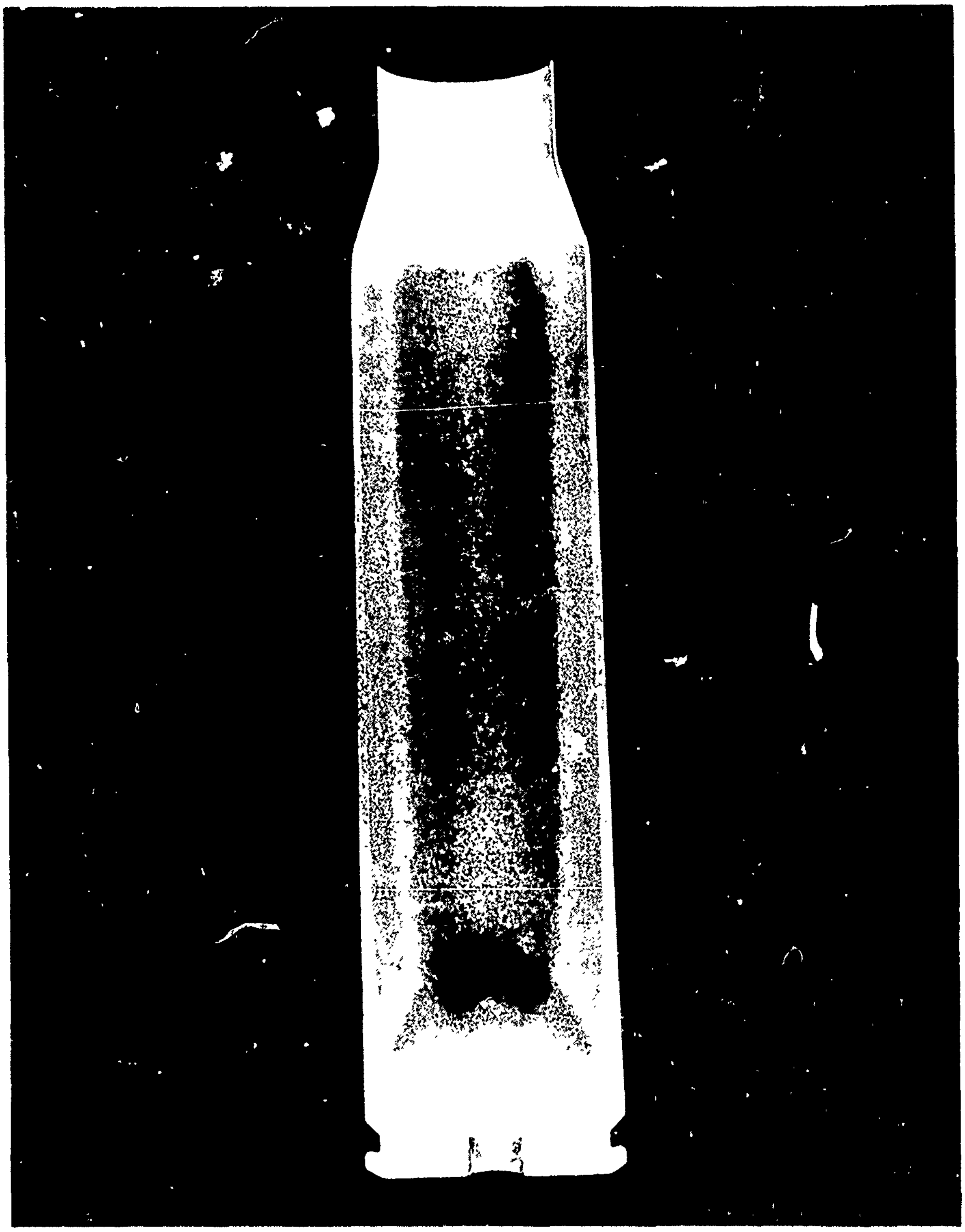


Figure 1 30mm Aluminum Cartridge Case

case datum line to bolt face have been established as restrictive guidelines for the gun designer.

The rear end of each cartridge case protrudes out of the barrel and is unsupported by the sidewall of the latter. Naturally, it is very desirable to hold the length of the unsupported case area to a minimum. Preliminary restrictive guidelines for the gun designer were established. Within the unsupported rear end of the cartridge case falls the area of the case extractor. The design study allotted sufficient space for a sturdy and strong extractor without sacrificing too much rear end support.

The final gun chamber design is shown in Figure 2, Chamber 30mm.

PROPELLANTS

1. General

The preliminary cartridge case design was based on the data provided in the RFP (projectile weight = 5,000 grains, muzzle velocity = 3,500 fps, and maximum chamber pressure = 60,000 psi) and the following calculations and assumptions.

2. Propellant Evaluation

The question of propellant type and characteristics was initially considered in order to establish the required case volume. This evaluation was developed as follows:

RFP Specifications: Projectile weight - 5,000 grains (0.7143 lb.)

Diameter - 30mm(1.1811 in.)

Muzzle velocity - 3,500 fps

Maximum chamber pressure - 60,000 psi

Calculated: $K.E. = \frac{W}{2g} V^2 = 0.7143 \times 3500^2/2\times32.174$

$= 135,975$ ft-lb. muzzle energy of projectile without propellant

Assumption: If the propellant translated 30% of its potential energy to emergence of the projectile from the muzzle, then 135,975/0.30 = 453,250 ft-lb. would be required from the propellant, and if a propellant contained 1,355,000 ft-lb. energy per pound, 453,250/1,355,000 = 0.334 lb. of propellant would be required. This converted to 0.334 lb. x 7,000 grains per lb = 2340 grains of propellant. Thus, 2340 gr/200 gr per cubic inch = 11.7 cu. in. for

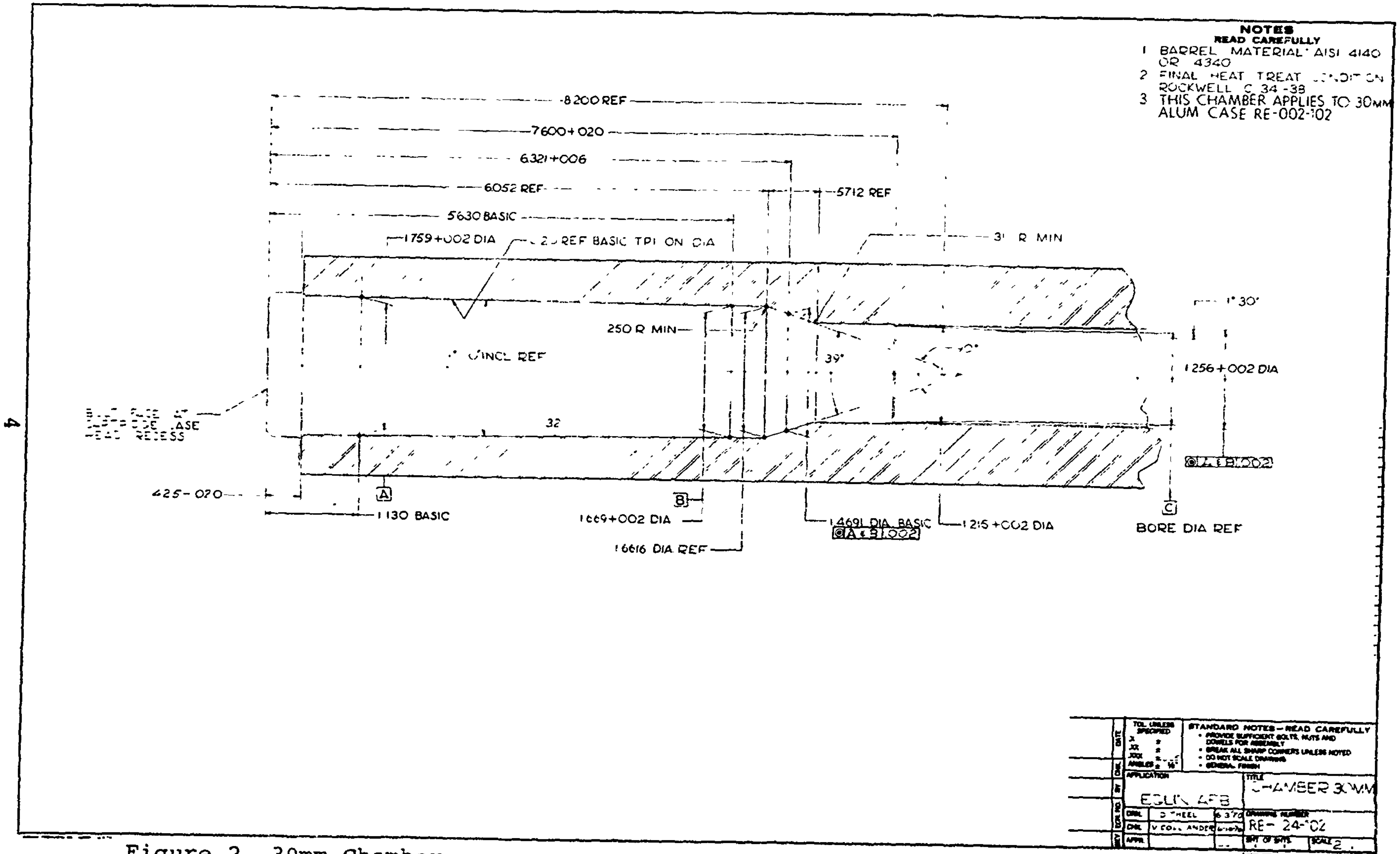


Figure 2 30mm Chamber

propellant, or 2340 gr/250 gr per cubic inch = 9.4 cu in. for propellant would be needed.

3. Suggested Propellants

Propellants suggested by propellant manufacturers were:

a. Olin Mathieson, East Alton, Illinois

WC-880 (Spherical Powder)

Volume - nearly 10 cu in. Weight - about 2100 grains Maximum Pressure - 53,000 psi	For 90 in. projectile travel
Volume - nearly 11 cu in. Weight - about 2350 grains Maximum Pressure - 58,000 psi	For 80 in. projectile travel

Action Time - 3.8 millisec.
Time-to-peak Pressure - 1.6 millisec.
Propellant Density - 0.96 g/cc (243 grains/in.^{3})

b. Hercules, Wilmington, Delaware

Hercules No. - HES6928

Volume - about 13 cu in. (for 85 in. projectile travel)
Weight - 2650 grains
Maximum pressure - 58,000 psi
Burn-out Time - 2.5 millisec.
Time-to-peak Pressure - 1 millisec.
Propellant Density - 227 grains/in.^{3}
Propellant Grain - 7% NG, d -0.02 in., OD- 0.15 in. L - 0.25 in., Cool Burning (2700°K, 2427°C, 4400°F), Methyl Centralite

c. Canadian Industries Ltd., Montreal, Quebec

Methyl Centralite (5.9%) with 0.024 to 0.27 in. web

Volume - 10 cu in. (85 in. from case head to muzzle)
Weight - 2250 grains
Maximum Pressure - 57,600 psi (3610 ft/sec and 0.0242 in. web)
Action Time - about 4 millisec
Time-to-peak Pressure - 1 to 1.5 millisec.
Propellant Density - 0.89 g/cc (225 grains/in.^{3})

d. Du Pont de Nemours, Wilmington, Delaware

IMR-8325 or IMR-8261M with loading densities of .92 and .95 gram per milliliter.

4. Actual

In actuality, the final firings used 2350 grains of C.I.L. 1379C. At .966 specific gravity, this occupies 9.62 cu in. Data for this propellant is shown in Table I.

TABLE I. PROPELLANT DATA

Manufacturer - Canadian Industries Limited
Type: SPDN Lot: EXP - 1379-C Batch No. 3739
Analysis of Nitrocellulose

Blends	% Nitrogen	% E/A. Sol.	K1 Test 65.5°C	Stability 134.5°C
C(1) 205	Average 13.11	35.80	36+	30

FINISHED PROPELLANT TEST DATA

Constituents	Composition Formula %	C.I.L.%
Nitrocellulose	Remainder	93.52
Methyl Centralite	6.0 Nominal	4.20
Diphenylamine	0.7 to 1.0	0.83
Pot. Sulphate	1.5 Maximum	.61
Lead Carbonate	0.6 to 1.0	0.84
Moisture	1.0 ± 0.25	1.00
Residual Solvent	1.1 Maximum	0.77
Volatiles Total	2.35 Maximum	1.77
Graphite	---	0.25
Dust and Foreign Matters	0.075 Maximum	0.01

GRAIN DIMENSIONS (in inches)

	Length	Diameter	Perforation Diameter	Mean Web
Die	.0909	.101	.015	-------
Finished	.0825	.0657	.0071	0.0293

The case volume behind the projectile was therefore chosen to be between 10 and 11 cu in. The case drawn for this proposal, as shown on RE-5-102 (Figure 3), contained approximately 10.7 cu in. behind the projectile.

The extra case volume was selected to provide for the following possibilities:

a. Heavier projectiles with same velocity

b. Higher velocity with same weight projectiles

c. Decreased velocities due to barrel erosion

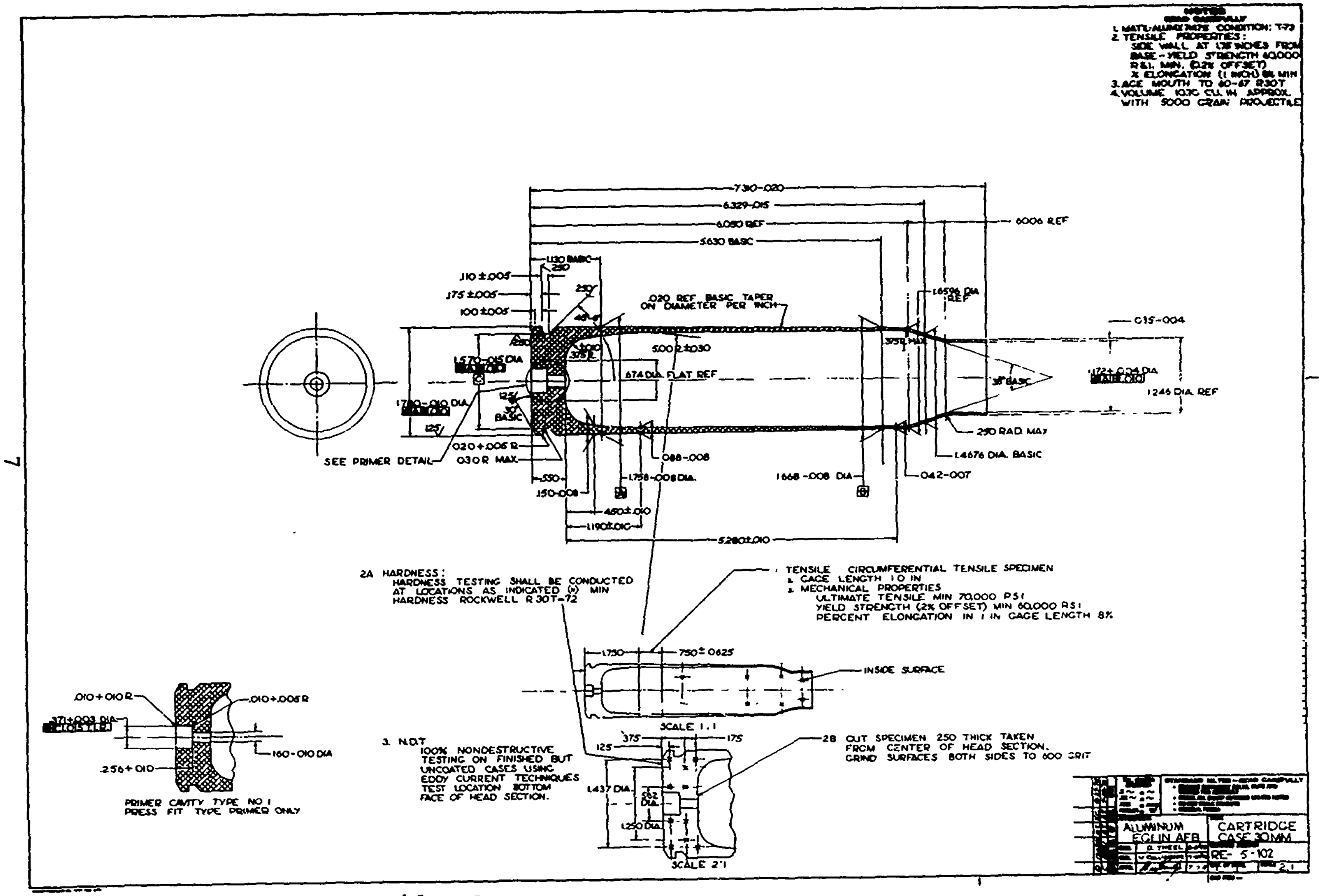


Figure 3 30mm Cartridge Case

d. Shorter barrel

e. Lower bulk density propellant

f. Recommended 14% of case volume as air space

g. Lower energy propellant

h. Increased projectile insertion into case

If none of these prove to be required or desirable, the case volume could be reduced up to 1.4 cu in. and the case length by 0.7 inches.

ANTICIPATED DESIGN DIFFICULTIES

No development program could be expected without its inherent difficulties; however, the probability of successful accomplishment of the development is enhanced if these difficulties are recognized beforehand. The development program for this 30mm aluminum cartridge case was no exception, and the following were recognized as possible problem areas:

1. Primer Setback, Primer Leaks, and Blown Primers

Difficulties of this type had been encountered in earlier efforts to develop aluminum cartridge cases as substitutes for existing brass or steel case designs. Severe primer leaks or blown primers result in varying degrees of hot gas erosion of the cartridge case head. Such difficulties are believed to be caused by undue expansion of the case head under pressure, surface irregularities in the primer pocket which were introduced during fabrication of the case or insertion of the primer, and inadequate design attention to the need for primer obturation.

The general approach to elimination of primer area difficulties was to recognize these potential problems in the design of the cartridge case head and primer pocket and to exercise due caution in producing a smooth primer pocket and keeping it smooth during primer insertion.

Further discussion of this problem is presented in the Test Firing section of this report.

2. Splits, Ruptures, and Case Erosion

Difficulties of this type had also been encountered in both earlier and current efforts to substitute aluminum for brass or steel designs. Either a longitudinal split or a circumferential rupture can lead to extensive hot gas erosion of the case and damage to the barrel. Such erosion is believed to be a split or rupture which occurred early in the interior ballistics cycle. Ruptures occurred mostly on caliber .50 cases made a decade ago, or earlier and were believed to have been caused by circumferential irregularities, sometimes called "shock lines, introduced into the case walls during fabrication. Ruptures were not a problem in the current efforts.

Splits were known to be associated with longitudinal discontinuities, such as tool scratches, and were believed to be associated with additional factors such as the notch toughness of the case material and the lack of uniformity and degree of lubricity of the exterior surface of the case. It seemed reasonable to suppose that such factors as chamber clearance and "crush up" could also contribute to these failures.

The general approach to eliminate splits and erosion was to select a notch tough alloy and temper, to recognize the potential problems when designing the case, to exercise due caution in producing cases free of metallurgical or mechanical discontinuities, and to develop a finish which would provide and maintain a uniform lubricity of the required degree over the entire surface of the case.

Firings of aluminum cartridge cases indicated that the aluminum industry's improvements in molten metal filtration techniques, ingot casting techniques, and controlled atmosphere annealing to reduce surface oxide have had the anticipated effect of reducing splits and erosion. Although the problem remained and there were no reliable predictions as to how extensive it would be on a new and different case, it seemed reasonable to expect its occurrence could be reduced to one per many thousand rounds and to make a determined effort to eliminate it entirely because of the seriousness of its consequences. This effort did not include the firing of enough rounds to fully test this.

Further discussion of this problem is also presented in the Test Firing section of this report.

MATERIAL SELECTION

In designing a cartridge case to meet the severe demands of an automatic aircraft cannon, the four stages of cartridge case life were given careful consideration. During the first stage a cartridge case must function as a package. It must protect its contents from damage through handling and environment, and it must have sufficient strength to retain a heavy projectile and a primer.

During the second stage of its life, the cartridge case becomes a working part of a highly complex piece of machinery. In this capacity, it must be closely dimensioned, and it must remain an integral structural unit as it passes through the weapon's feeder mechanism. Depending on the design of the weapon, the cartridge case may be expected during feeding to receive severe blows and travel at high rates of speed with sudden stops, and yet retain its structural integrity.

The third stage is the actual firing. The cartridge case is expected to function as a high pressure vessel, to obturate, to return to a configuration smaller than the weapon's chamber, and to be easily extracted. During this state, the case is expected to produce minimal wear, leave no residue, and be free from fractures.

The fourth stage completes the cycle with the cartridge case passing through the ejection system and becoming scrap material.

If the customary cartridge case materials are considered in the light of the above criteria, it is apparent that each material has its own strengths and weaknesses. Cartridge brass, for example, performs fairly well as a packaging material but is subject to severe corrosion in some environments and lacks sufficient strength to withstand abusive handling. As a machine part, brass has optimum properties, and when properly supported, performs well as a high pressure vessel, but is undesirably heavy within the context of an aircraft system where weight is important. In the fourth category, that of becoming scrap metal, lies another major area of disadvantage due to the high cost and the resulting loss of brass as a strategic material. In contrast, a heat-treated steel cartridge case provides an optimum packaging material, particularly when plated with zinc to provide cathodic protection. A steel case functions well as a machine part and as a high pressure vessel but does produce greater wear on the mating surfaces of the weapon. The weight of the steel case, as with brass, is a disadvantage from the standpoint of the load in an aircraft. As scrap, steel is excellent since it does not represent any great loss of strategic materials.

Aluminum seems to fulfill all of the desirable features for a cartridge case material. In the higher strength heat-treatable alloys, suitable mechanical properties are developed to give "package-ability"; with the application of suitable coatings and heat treatments, the cases can be expected to stand up well under handling and environmental conditions. Unfinished aluminum's tendency to gall and seize in contact with moving steel parts and the abrasive nature of an anodic coating, combined with the obvious shift in the center of gravity of the round, may present a problem in existing feeder designs. Therefore, the use of lubricant-impregnated coating alleviates part of the problem, but the center-of-gravity difference must be considered and allowed for during weapon design. Aluminum cartridge cases have successfully functioned as high pressure vessels.

The tendency for a cartridge case to stick in the chamber and cause extraction problems is primarily a function of:

- the material modulus of elasticity;
- the radial clearance between the cartridge case and chamber wall;
- the thickness of the chamber;
- the taper of case and chamber; and
- the coefficient of friction between the cartridge case and the chamber wall.

CARTRIDGE CASE DESIGN CRITERIA

1. Propellant Weight

Propellant Weight - 2340 grains

2. Case Volume

$$\text{Case Volume} = \frac{\text{Propellant Weight}}{\text{Estimated Propellant Density}} = \frac{2340 \text{ grains}}{225 \text{ gr/cu in.}}$$

$$= 10.40 \text{ cu in.}$$

3. Maximum Working Chamber Pressure

Maximum Working Chamber Pressure = 60,000 psi x 1.14 (Safety Factor)

= 68,400 psi

4. Maximum Cartridge Case Diameter at Head

The final design (Figure 3) shows a maximum case outside diameter of 1.78 inches although earlier calculations began with an outside diameter of 1.92 inches. With a case outside diameter of 1.92 inches, the wall thickness of the barrel would be approximately 0.73 inch. Since gun weight would be excessive under these conditions, the case chamber diameter was reduced to 1.75 inches (while the volume was kept constant), permitting a significantly smaller barrel wall thickness of 0.57 inch minimum at the chamber. This relationship, which is illustrated graphically in Figure 4, limits chamber wall deflection to 0.004 inch on the radius.

5. Case Material

The following data, supplied by Alcoa, are applicable to X7475 alloy in*T73 condition:

Typical Tensile Strength (ultimate)	=	72,000 psi
Typical Tensile Yield Strength	=	62,000 psi
Typical Shear Strength	=	43,000 psi
Modulus of Elasticity	=	10.4×10^6 psi

6. Muzzle Energy

$$\text{Muzzle Energy} = \frac{W}{2g} V^2 = 136{,}000 \text{ ft-lb}$$

W_b = Projectile weight (lb)

V_o = Muzzle velocity (ft/sec)

g = Acceleration of gravity (ft/sec^2)

*T73 is a patented Alcoa process

Wall Thickness Calculated with a Chamber
Deflection of .008 in. on the Diameter

$$\Delta A = P\frac{A}{E}\left[\frac{B^2+A^2}{B^2-A^2} - \nu\left(\frac{A^2}{B^2-A^2} - 1\right)\right] = .004 \text{ IN.}$$

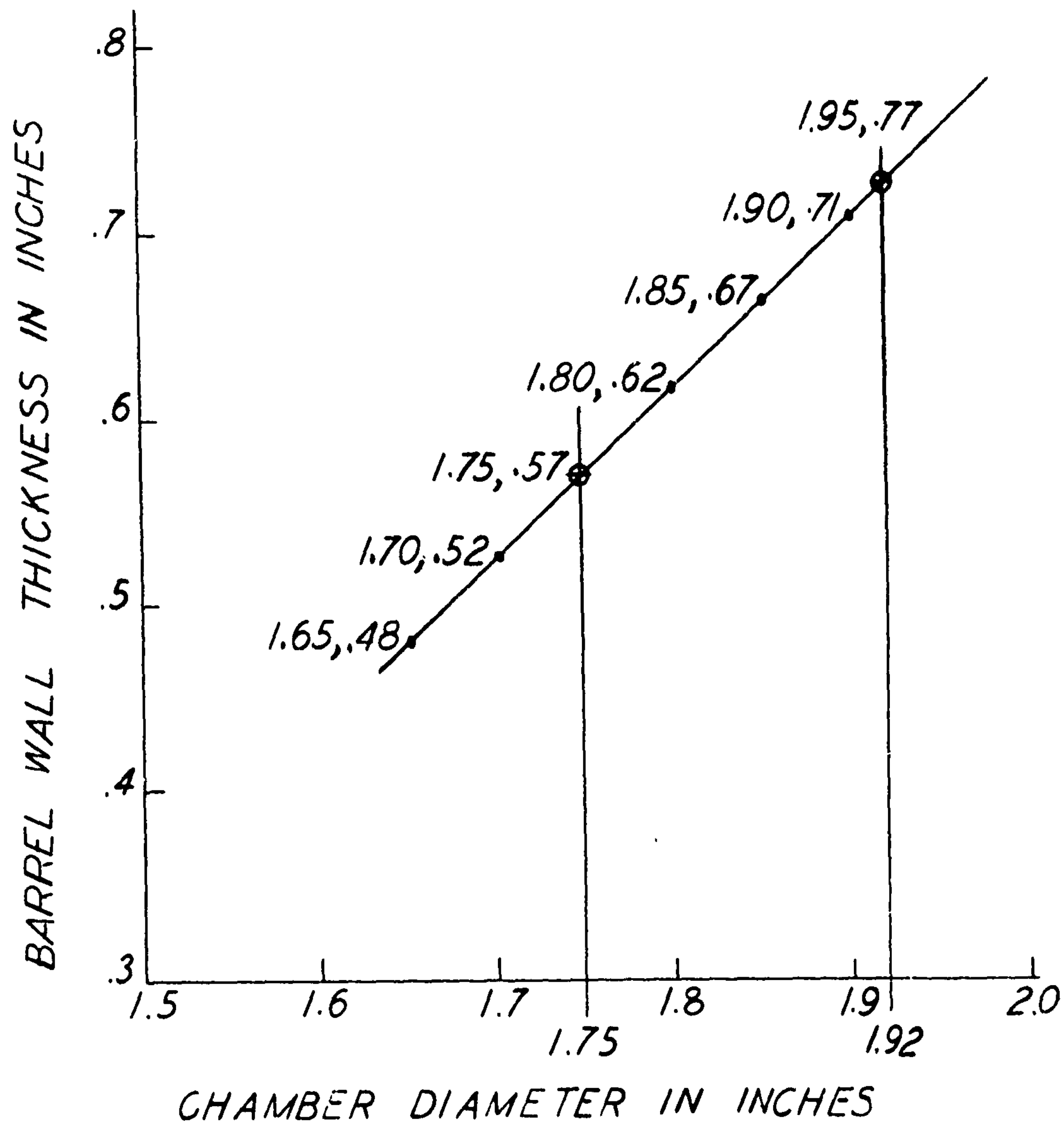


Figure 4 Chamber Diameter Versus Barrel Wall Thickness at 1.130 in. Base Diameter Location on Cartridge Case

7. Muzzle Impulse

$$I = \frac{W_b V_o}{g} + \frac{W_p V_o}{2g} = 96.00 \text{ lb/sec}$$

W_b = Projectile weight (lb)

V_o = Muzzle velocity (ft/sec)

W_p = Propellant weight (lb)

g = Accerleration of gravity (ft/sec^2)

DIMENSIONAL CHARACTERISTICS

1. General

The dimensional characteristics can certainly be determined during the design phase of the weapon. The coefficient of friction appears to be most favorable, based on recent tests conducted by the Alcoa Research Laboratories, where the aluminum, with suitable surface treatments, has a coefficient considerably below that of either zinc-plated steel or cartridge brass. If the alloy used and the design of the cartridge case are correct, the only detrimental feature would be the lower tear strength/yield strength ratio. This ratio describes the ability of a material to resist propagation of cracks in either an elastic or plastic stress field. The curves shown on Figure 5 are taken from current research work being conducted at the Alcoa Research Laboratories and show the relationship between cartridge brass and possible aluminum alloys under consideration for use in cartridge case manufacture. Improving the characteristic of this ratio through modification of chemistry and processing techniques was accomplished.

a. Explanation of Engineering Curve (Figure 5 Tear Strength/Yield Strength Ratio)

The curves shown illustrate one of the characteristics which is felt to be the key to success in the utilization of aluminum for cartridge case manufacture. The curves show the relationship between tear strength and yield strength of various aluminum alloys and various heat treatments in relation to the same characteristic in 70/30 cartridge brass. The data were obtained using sheet specimens, conventional for yield strength, and notched specimens for tear strength measurements. The specimens had been rolled to various dimensions and selectively heat-treated to represent various areas of a brass 20mm cartridge case design.

The continuous line, identified Al-Zn-Mg T6, represents the present behavior for this alloy system, and the dashed line, identified Al-Zn-Mg 1.5 Cu, establishes the behavior for that alloy system.

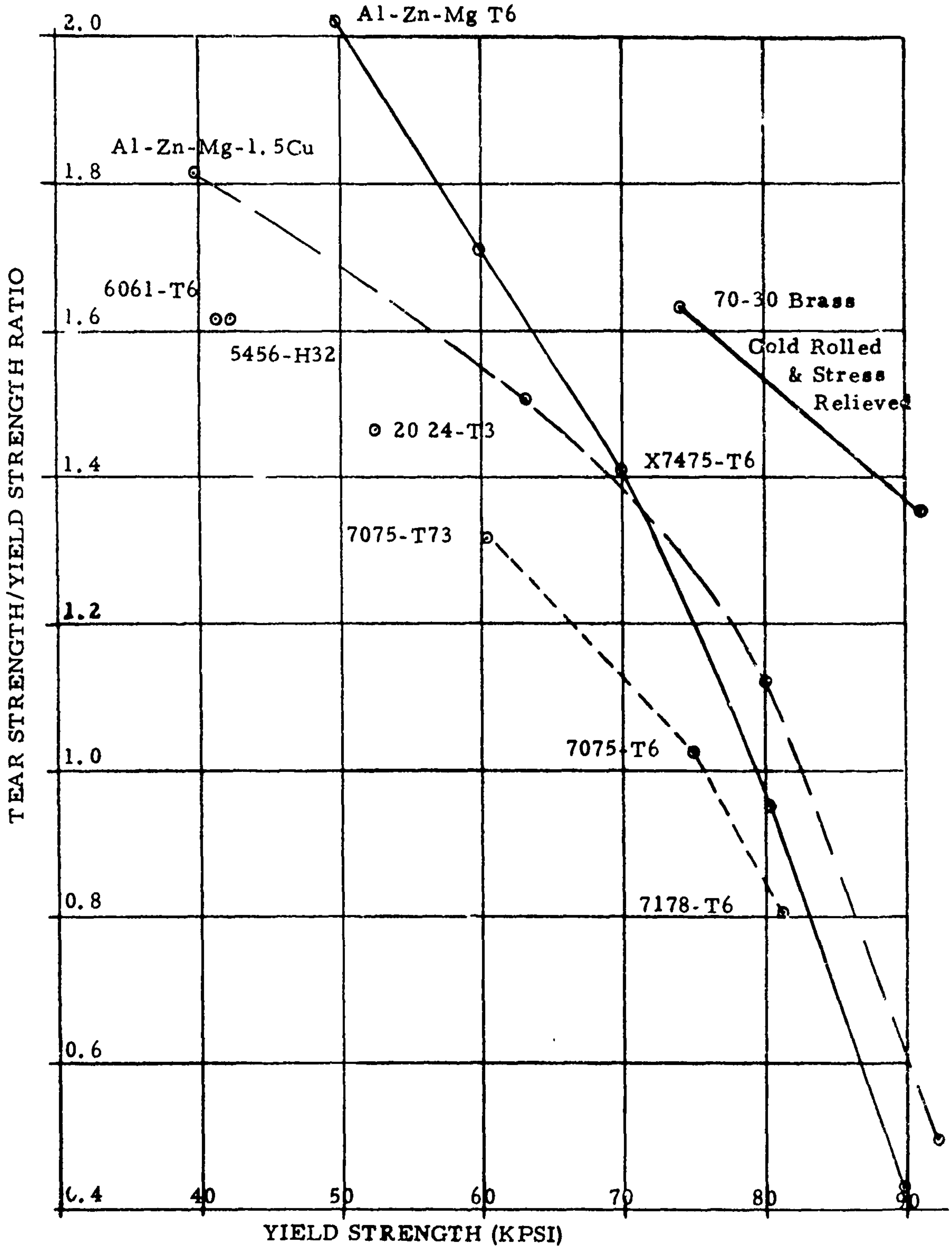


Figure 5 Tear Strength/Yield Strength Ratio Versus Yield Strength

The selection of X7475 (selected chemistry 7075) becomes obvious from a study of its relationship to the limits of its alloy system. The use of a T73 heat treatment will shift the point shown for T6 slightly higher and to the left.

The traditional problem of stress corrosion cracking, encountered with high strength aluminum alloys, has been essentially overcome through the use of the T73 , a two-step aging treatment. Tear/yield curves illustrate this effect of treatment on mechanical properties. In general, it is considered that the mechanical and physical properties of aluminum, combined with modern finishing techniques, give aluminum every chance and possibility of success for use in the manufacture of automatic aircraft cannon cartridge cases.

The selection of the alloy to be used became a fairly straightforward decision when the physical and mechanical properties of the available alloys were screened using the criteria listed above. The alloys which had already been considered were 6066, 2024, and 7075. Such factors as adequate ductility, final strength levels, susceptibility to stress corrosion, availability, compatibility with finishing methods, natural aging tendency, sensitivity to processing tolerances, etc., lead rapidly to the conclusion that the "right" alloy was X7475 (a modified 7075 alloy), heat-treated to condition T73. The modifications of chemistry represented by the alloy, now designated X7475, was a restriction of the chemical limits of 7075 and does not present a problem for future procurement from multiple sources. The practice of limiting chemistry and impurity levels within the published ranges of materials is a common practice in the marketing of high strength 7000-series aluminum alloys.

2. Cartridge Case Configuration

With regard to cartridge case configuration, the traditional problem of meeting propellant volume requirements without an exaggerated length-to-diameter (L/D) ratio had to be considered. As the length of the cartridge case increases to satisfy propellant volume requirements, the problems in gun feeder design increase. As the diameter of the cartridge case increases, the effective stress increases, tending to rupture the case on its circumference; in addition, the size and thickness of the weapon chamber become prohibitive. If an aluminum cartridge case is to function properly in an automatic gun, the L/D ratio must be carefully established to provide optimum volume along with proper frictional holding forces during the pressure rise, and there has to be a sufficient sidewall strength to prevent longitudinal and circumferential rupture throughout the firing cycle. The final L/D ratio and the powder volume dictate the cartridge case wall and head dimensions. The sidewall dimensions must be carefully designed to produce the proper incremental obturation and frictional lockup beginning at the mouth of the case and ending at the extractor groove relief. If this

design fundamental is not carefully observed, the case cannot "grow" in longitudinal direction and a segment of the case will be placed in a triaxial stress, permitting a fracture during the initial pressure rise. The wall thickness must also be considered in the relationship of gun chamber clearance and the amount of elastic deformation allowed by the design of the gun chamber. If this design fundamental is ignored, longitudinal cracks can occur. The head section dimensions are critical from the standpoint of the ability to withstand the imposed internal stresses in the unsupported case section in the extractor groove area; the ability to expand under the imposed stresses and retention of the primer, and the ability to return to dimensions which will continue to provide clearance for extraction and primer retention. Some of these characteristics are illustrated by the curves in Figure 7 that show the behavior of steel and aluminum cartridge cases under conditions imposed in 20mm automatic aircraft guns, as generated by the time-pressure conditions illustrated in Figure 6.

a. Explanation of Curves (Figures 6 and 7)

The curve on Figure 6 illustrates the typical time-pressure curve for a steel-cased 20mm round. As noted, this information was gained using a 20mm Mann barrel and an IMR standard propellant load.

Figure 7 illustrates the factors which must be considered in the design of new cartridge cases. As noted, three characteristics are most important:

(1) The minimum obturating pressure: This is defined as the minimum pressure that would cause a given area of a cartridge case to expand and just touch the chamber wall. This curve is a function of the material modulus and the case diameter.

(2) The minimum pressure for case separation: This curve shows the required chamber pressure to cause the case to separate circumferentially, assuming there is no rearward support. The curve is a function of the ultimate tensile strength of the material and the case dimensions.

(3) The interfacial radial strength at 60 KPSI internal pressure: This curve illustrates the force holding the cartridge case against the chamber wall at maximum chamber pressure. The component of force multiplied by the coefficient of friction gives the theoretical force or pressure required to withdraw the case from the chamber. It is important to note that this curve is a function of pressure and dimensions and is independent of the cartridge case material.

By utilizing this information, a cartridge case was designed that can successfully withstand the stresses imposed and does return to dimensions suitable for proper extraction. This information also leads to accurate computation of the maximum pressure that can be used but prevents case failure during the unlock and extraction portion of the cycle.

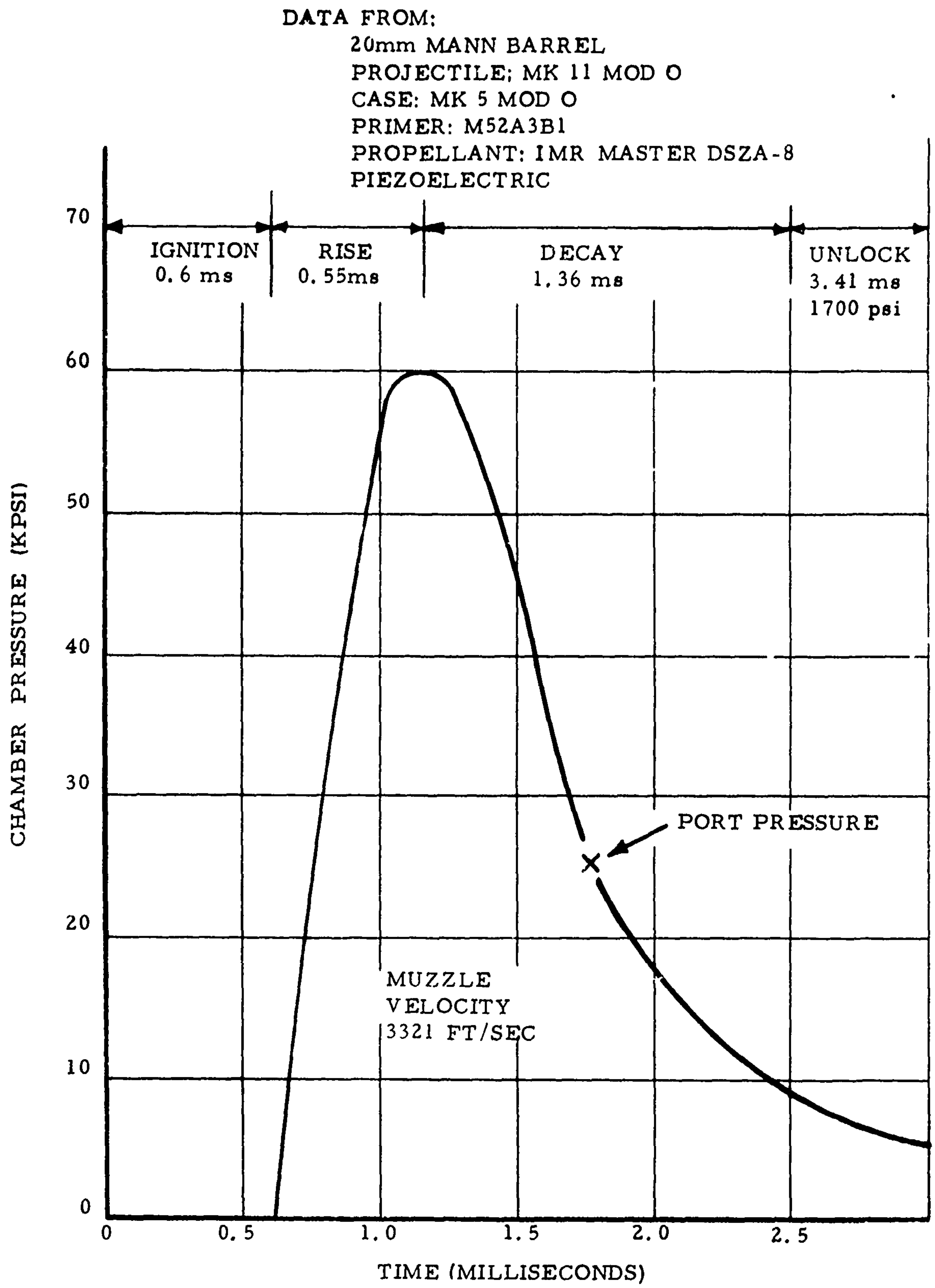


Figure 6 Typical Time/Pressure Curve

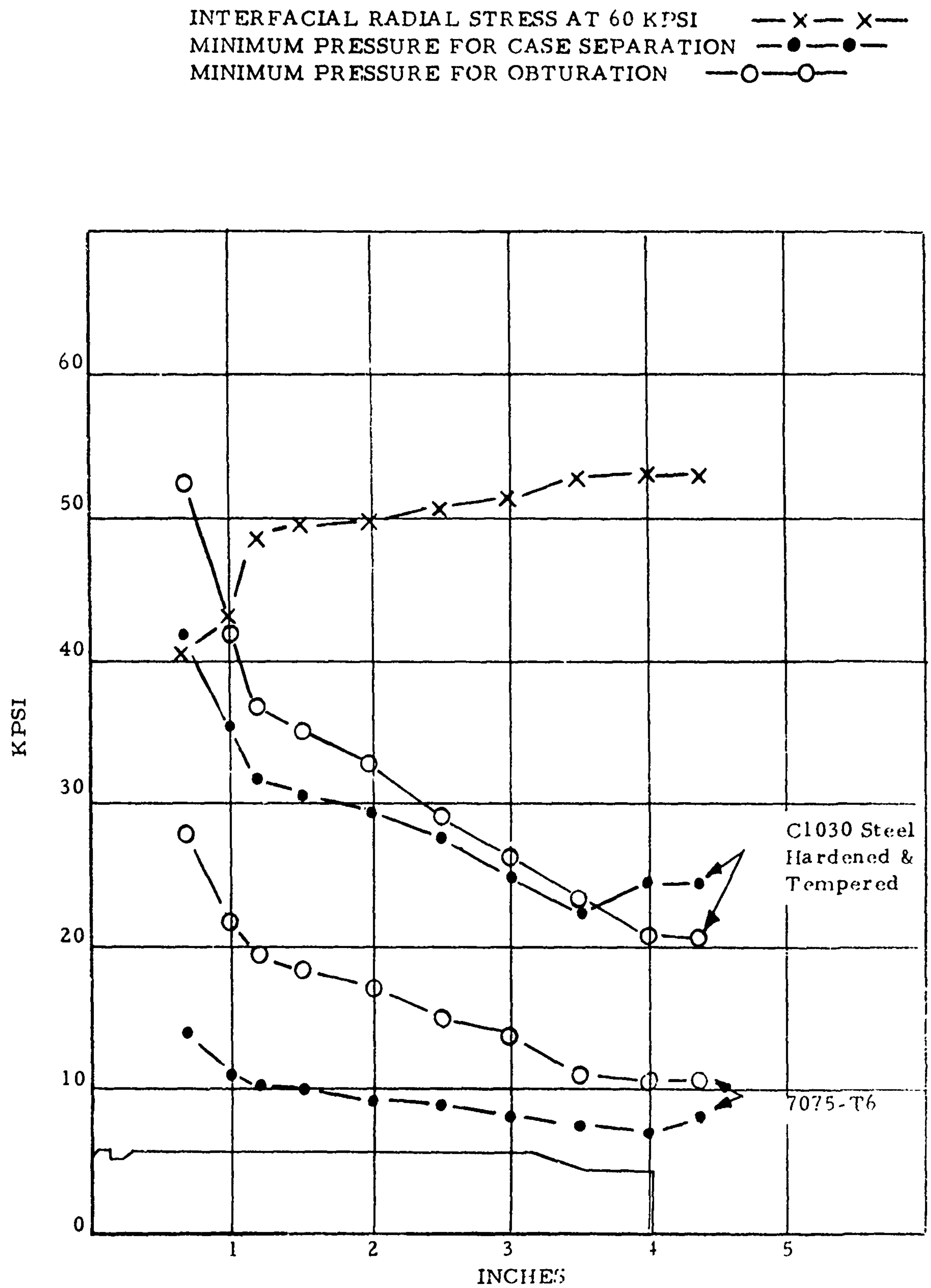


Figure 7 Three Case Design Factors

DESIGN ANALYSIS

In order to prove the validity of the design previously depicted on Figure 3, static stress calculations were conducted as shown:

1. Chamber Wall Expansion

Calculation in Figure 8 shows the chamber expansion to be .004 in., assuming a chamber pressure of 60,000 psi and barrel material FS4150 (MIL-S-46047) are being used.

2. Stress in Chamber Wall

Calculation in Figure 9 shows the stress in the barrel chamber wall, under the expansion of .004 in., to be 137,142 psi tensile strength. The stress condition is within the strength of the barrel material FS4150 (MIL-S-4607) in heat-treated condition R_c32-36.

3. Stress Check of Case Base

Calculation in Figure 10 shows the shear stress in the case base to be 44,030 psi.

SURFACE FINISH

The surface finish was of prime importance to the successful completion of this program. The problems of cartridge case cracking, general corrosion, retention of primers, and proper extraction characteristics made the subject of surface finish worthy of a correlative study.

A suitable surface finish, correlated to the alloy required for the desired mechanical and fabricating properties, must produce corrosion resistance, lubricity, propellant compatibility, abrasion resistance, flexibility, and retention of initial appearance on the aluminum case body. Thus, the development of an optimum finish was a vital part of the total program for utilizing the advantages of aluminum in this application. A further discussion of surface finish is given in Section V, Surface Finish.

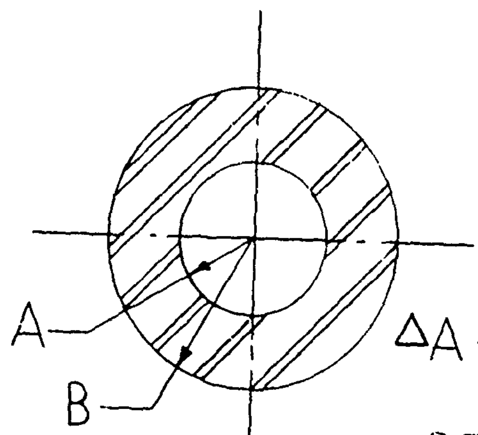
SHORTER CARTRIDGE CASE DESIGN

In October, 1969, at the request of the Air Force Armament Laboratory, a design investigation to shorten the cartridge case was carried out by making the following basic changes:

1. The base diameter was increased by .110 in.

2. The sidewall taper was increased to .024 in. basic taper per inch on diamter.

3. The shoulder included angle was decreased to 38°.



CHAMBER

$$\Delta A = P\,\frac{A}{E}\left[\frac{B^2 + A^2}{B^2 - A^2} - \nu\left(\frac{A^2}{B^2 - A^2} - 1\right)\right]$$

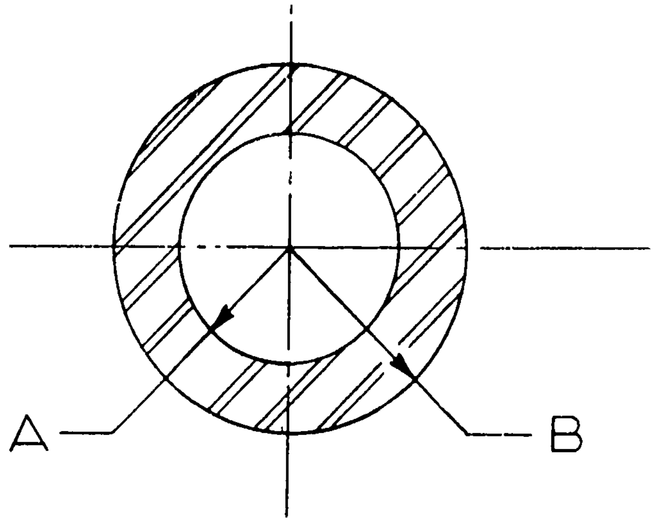
REF. "FORMULAS FOR STRESS AND STRAIN" BY ROARK. PAGE 276 CASE NO. 29.

A = CHAMBER RADIUS = .875 IN.
P = CHAMBER PRESSURE = 60,000 P.S.I.
E = MODULUS OF ELASTICITY = 30×10^6
B = BARREL OUTSIDE RADIUS = 1.4 IN.
ν = POISSON'S RATIO = .26

$$\Delta A = 60{,}000\,\frac{.875}{30 \times 10^6}\left[\frac{1.4^2 + .875^2}{1.4^2 - .875} - .26\left(\frac{.875^2}{1.4^2 - .875^2} - 1\right)\right]$$

ΔA = .003942 OR .004 IN.

Figure 8. Chamber Wall Expansion



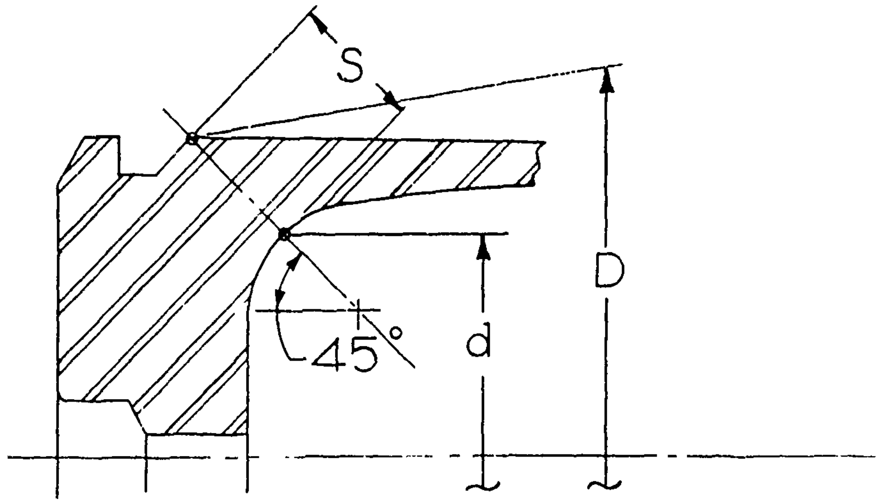
$$E = \text{MODULUS OF ELASTICITY} = 30 \times 10^6$$

$$E = \frac{\text{STRESS}}{e/A} \qquad e = \Delta A = .004 \qquad A = \text{CHAMBER RAD.} = .875$$

$$\text{STRESS} = \frac{30 \times 10^6 \; (e)}{A}$$

$$\text{STRESS} = \frac{(30 \times 10^6)\;(.004)}{.875} = 137{,}142 \text{ P.S.I.}$$

Figure 9. Stress in Chamber Wall



CALCULATED AS A CONICAL SHEARING SECTION EXTENDING INTO EXTRACTOR GROOVE AT 45°.

AREA OF CONICAL SURFACE OF FRUSTUM OF A CONE IN SHEAR $A = 1.5708\,S(D+d)$

$$\text{SHEAR STRESS} = \frac{P\ \pi\ d^2}{(4)\ (1.5708)(S)\ (D+d)}$$

P = MAXIMUM CHAMBER PRESSURE=70,000 PSI
d = SMALL DIAMETER OF FRUSTUM OF CONE=1.2 IN.
S = LENGTH OF CONICAL SURFACE= .386 IN.
D =LARGE DIAMETER OF FRUSTUM OF CONE=1.75 IN.

$$\text{SHEAR STRESS} = \frac{(70{,}000)\ \pi\ (1.20^2)}{(4)\ (1.5708)\ (.388)\ (1.75+1.20)}$$

SHEAR STRESS = 44,030 P.S.I.

THIS CALCULATION SHOWS THAT THE SHEAR STRESS AT THE CARTRIDGE BASE IS BELOW THE STRENGTH OF X 7475 -T 73 ALUMINUM ALLOY.

Figure 10. Stress Check of 30mm AX Case Base

The objective of the above-mentioned changes was to reduce the overall length of the cartridge case .50 inch without decreasing the interior volume an appreciable amount. No further engineering work was carried out on this shortened case because the advantage of length reduction was not great enough to balance the disadvantages incurred by the increase in barrel diameter.

PROPOSED REDESIGN REQUESTED BY THE AIR FORCE

The first case redesign was designed with a base diameter of approximately 44mm. The volume of the case was calculated to be 10.2 cu in. The redesign and the original case design were presented to the Air Force during a review meeting on 19-20 August 1969. However, the RE-5-102 case (Figure 3) was accepted for the design of tools and gages and the fabrication of cases. The larger volume of the original design was considered better because of the flexibility required for propellant selection.

INTERIOR CASE VOLUME REDUCTION

Part of the design evaluation was to attempt to reduce the volume required for propellant so that the case could be shortened. The final propellant charge was established as 2350 grains, which, if the assumption is made that the approximate loading density is 240 grains per cu in., requires a propellant volume of 9.8 cu in. There are several disadvantages in having excess volume in a cartridge case, namely,

1. Ignition problems, when all the propellant is driven forward from the flash hole as the round is chambered during the feeding cycle.

2. Unnecessary cartridge length resulting in extra weight and gun feeding problems. In order to minimize the case volume, a 6% clearance volume was assumed to be sufficient. The following computation shows what the interior volume requires:

Volume for propellant	9.8 cu in.
Clearance volume	0.6 cu in.
Volume of projectile base	1.0 cu in.
	11.4 cu in.

Since the Amron AX case now has 12.0 cu in. total volume excluding the primer cavity and flash hole, 0.6 cu in. could be eliminated.

SECTION II

MATERIAL

GENERAL

The material used for the 30mm cartridge case program is the Alcoa alloy X7475. The purchased temper is OE4 which is a special full anneal temper. This temper imparts the maximum ductility and thereby precludes the need for extensive and costly long-cycle process annealing.

RAW MATERIAL

X7475 Chemical Composition

Silicon	Iron	Copper	Manganese	Magnesium
0.10% max.	0.12% max.	1.2 - 1.9%	0.06% max.	1.9 - 2.6%

Chromium	Zinc	Titanium	Others	Aluminum
0.18 - 0.25%	5.2 - 6.2%	0.06% max.	Each 0.05% Total 0.15%	Remainder

The as-received plate material has a fine grain size and a Rockwell Hardness of R_H92-93.

Incoming inspection activities included, but were not limited to, the following:

1. Check analysis of key elements using Atomic Absorption Spectrophotometer Techniques.

2. Rockwell hardness testing.

3. Metallurgical micro- and macroexamination.

4. Determinations of percent IACS.

METALLURGICAL PROCESSING

After discs were blanked from the plate, they were annealed at 630° - 675° F for 30-90 minutes, resulting in a Rockwell core hardness of R_H89 - 87.

The lubrication process for the metal-forming process through third draw was that of a precleaned surface, followed by an application of a zinc phosphate substrate overlayed and impregnated by a lubrication coat of zinc stearate. Specific chemicals used were as follows:

1. Pre-cleaning - Wyandotte Aldet

2. Zinc phosphate - Bonderite 170X

3. Zinc sterate - Bonderlube 234

4. Post-cleaning - Oakite 33

All subsequent lubrication was conducted using the aforementioned pre- and post-cleaning supplemented with a basic solution of Swift Soap Chips at a concentration of 12 - 16 oz/gallon.

Studies conducted indicated that other lubricants, as produced by Irmco, E. F. Houghton, Texaco, and Johnson's Wax, were promising but did not offer any marked improvement in performance over that initially selected for use. A study of the mass producibility could well show the need for a lubricant easily applied by the dip or immersion process and imparting the same excellent surface finish but which would be more economical and one which could be cleaned in a more straightforward manner.

In-process annealing was conducted at 630^{o} - 675^{o}F for 30 - 90 minutes. Resulting hardnesses were in the range of the R_H90 - 95. Starting hardness for the cold worked parts was in the range of R_H94 - 98.

The metallurgical quality of X7475 alloy is considered superior to that of any other alloy suitable for use in making aluminum cartridge cases. The cleanliness of the metal and the fine grain size contribute to this feature. The highly innovative Alcoa 467 process is directly responsible for the alloy's superior fracture toughness. This process was developed specifically to enhance the toughness of high purity 7000-series alloys (Al-Zn-Mg-Cu series). The mechanical properties features of the cartridge cases are discussed in Section I of this report.

Some time limitations were observed on parts subjected to the process anneal relative to the time delay between annealing and cold working. The time limit appears to be approximately 72 hours and affects the concept of high productivity, but it can be compensated for by proper scheduling.

The solution heat treatment which results in minimized stress corrosion susceptibility was conducted in a Pacific Scientific solution heat treatment furnace designed exclusively for high quality aluminum alloy cartridge cases. This furnace is provided with a unique protective atmosphere which inhibits harmful oxidation. Quench delay times into cold water can be kept within 4 - 7 seconds. Artificial aging is conducted in a high rate recirculation oven. Approximate heat treatment times and temperatures follow:

Solution	880^{o} - 950^{o}F
Time	30 - 120 minutes

Quenchant	50^{o} - $85^{o}F$ Water
Artificial aging	$250^{o}F$ - $325^{o}F$ with time ranges from 24 hours at $250^{o}F$ to 5 and 8 hours combinations at 250^{o} and $325^{o}F$.

PROPERTIES

Typical mechanical properties follow:

	Yield	Ultimate	Percent Elongation	R_{30T}
X7475-T6	73,000	83,000	10	74
Preferred X7475-T73	62,000	72,000	8	74

Generally observed tear strength/yield strength ratio is 1.2 at a yield strength of 75,000 psi.

Alloy X7475 can be processed through metallurgical operations without difficulty, and physical/mechanical properties can be tailored to those needed to provide high quality aluminum cartridge cases for the T73 temper.

Raw material should be purchased as plate at proper thickness of alloy X7475 - OE4 Temper, fine grain size, ar , of cartridge case quality.

Chemical composition limits of X7475-T73 are given in this section of the report.

Minimum hardness measured at the internal portions of the head section and throughout the wall section shall be R_{30T} 72 minimum. The mechanical properties of tensile and percent elongation, measured at a point 1.5 to 2.0 inches from the face of the head section, shall be:

Ultimate psi minimum	Yield psi (.2% offset) Minimum	Percent Elongation (1 in. gage) minimum
70,000	60,000	8

SECTION III

MANUFACTURING PROCESS

GENERAL

Production of a ballistically successful aluminum cartridge case for the 30mm program depends heavily on a careful selection of the correct alloy and of the quality control measures in monitoring each of the operations. The backward extrusion from rod method of manufacturing was investigated but the blank, coin cup and draw process was chosen as the most appropriate and economical method for high production, high volume of manufacturing.

A few advantages other than the economical ones are the following:

1. Superior physical properties were obtained in the critical head section because of the loop grain flow.

2. The fact that the metal that will form the sidewall was placed in circumferential and longitudinal tension during the drawing operation makes the process self-cleansing, because any serious mechanical or metallurgical flaws will physically destroy the part or it becomes an easy visual rejection.

MATERIAL

Raw material was received in strip form, and discs were blanked from these strips. This gave the necessary loop grain flow in the head section of the case.

MANUFACTURING PROBLEMS

1. Blank

After manufacturing a few blanks, it was discovered that there was insufficient clearance between the punch and die. The punch had to be reground several times before the proper clearance was established.

2. Coin Cup

After tool tryout of this operation, it was felt that the base thickness was insufficient for the heading operation. Therefore, the angle of the punch had to be regound in order to trap more material in the die. This was accomplished with the first try and produced the necessary base thickness.

3. First through Fourth Draw

Tool tryout of these operations proved to be no problem, and everything went through a smooth manufacturing process.

4. Head and Indent Primer Cavity

After heading and indenting a few cases, they were heat-treated to see whether the primer pocket would change during the heat-treating process. After the heat-treating process, the cases were rechecked and the primer pocket had not changed.

5. Head Turn and Drill Flash Hole

This operation presented no problem. All that was necessary was to check the part and maintain the correct speed and feed recommended for the tooling.

6. Pre-taper and Taper

In order to prevent any distortion in the final configuration of the cartridge case, it was necessary to go to a pre-taper prior to final tapering of the case. The case was pre-tapered and then heat-treated. After heat-treating, the case was final tapered.

7. Photograph

Figure 11 illustrates the manufacturing operations discussed in the preceding paragraphs.

PROCESS DEVELOPED

Table II Operational Summary, lists the operations necessary to produce the 30mm aluminum cartridge case.

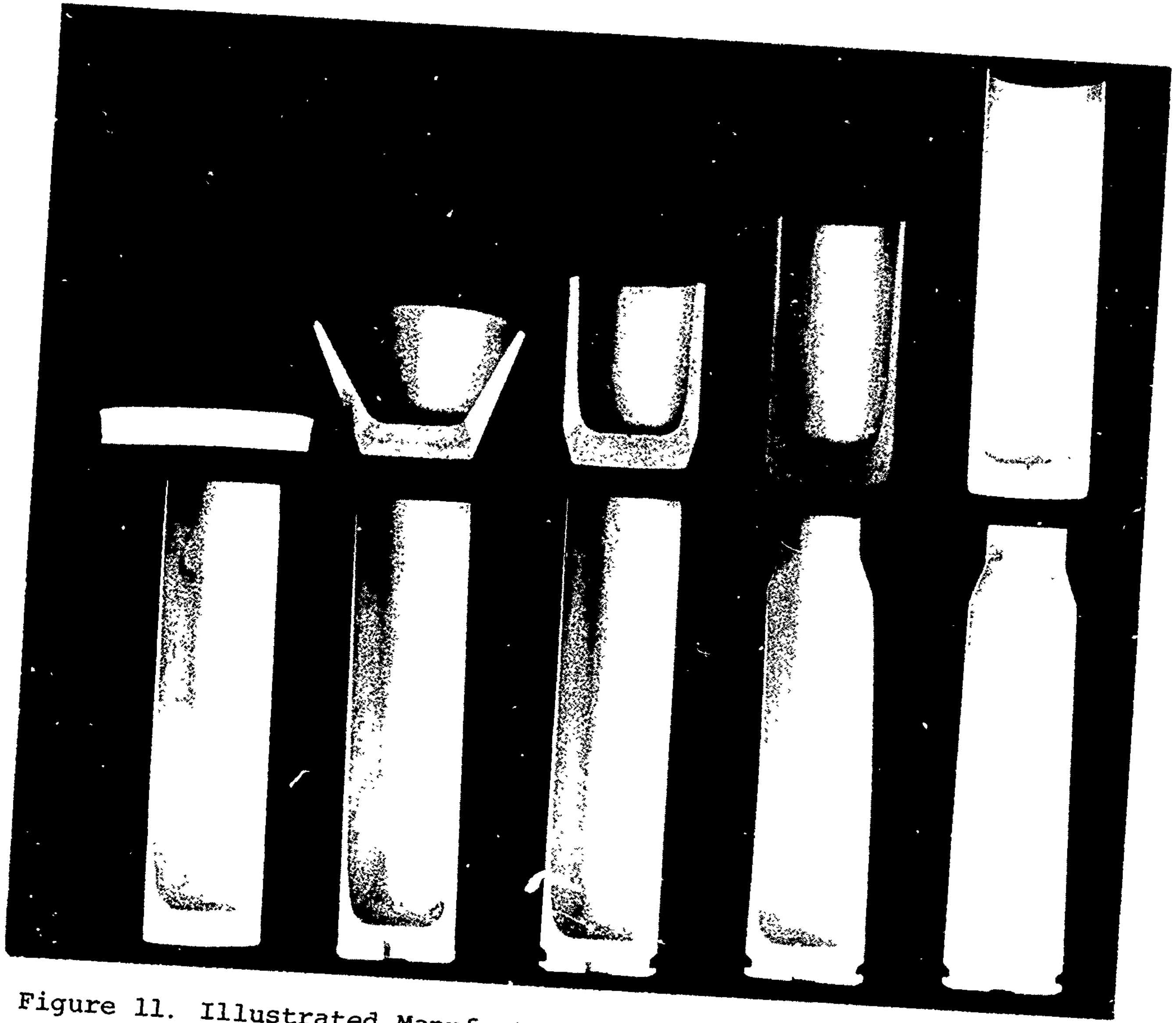


Figure 11. Illustrated Manufacturing Operations

TABLE II. OPERATIONAL SUMMARY

Operation Number	Operation Description
10	Receive and check order
20	Receiving inspection
30	Blanking
40	Wash
50	Anneal blanks (Condition "O")
60	Bonderize and Bonderlube
70	Coin cup
80	Wash cups
90	Anneal
100	Bonderize and Bonderlube
110	1st Draw
120	Wash
130	Anneal
140	Bonderize and Bonderlube
150	2nd Draw
160	2nd Draw Trim
170	Wash
180	Anneal
190	Bonderize and Bonderlube
200	3rd Draw
210	3rd Draw Trim
220	Wash
230	Anneal
240	Bonderize and Bonderlube
250	4th Draw
260	4th Draw Trim
270	Head and Indent Primer Cavity
280	Head Turn and Drill Flash Hole
290	Wash
300	Anneal
310	
320	Pre-taper trim
330	Pre-taper

TABLE II. OPERATIONAL SUMMARY (Concluded)

340	Wash
350	Heat Treat T-4
360	
370	Taper
380	Final Wash
390	Artificial Age
400	Final Trim
410	Mouth Age
420	Size Mouth
430	Final Hardness and Tensile Test
440	Anodize
450	Mark
460	Final Inspection Final Insp. - Lot Verification-Sampling Final Insp. - Lot Verification-Sampling Final Insp. - Lot Verification-Sampling Final Insp. - Salt Spray Test Final Insp. - Hardness Test
470	Pack and Store Prior to Assembly

SECTION IV

IGNITION SYSTEM

GENERAL

An ignition system was developed around Frankford Arsenal 20mm XM-115 primer that suited the pressure-time curve of the propellant burning.

If the primer had been too small and generated insufficient pressure and flame to ignite enough propellant within the proper time frame, "hang fires" could have resulted.

On the other hand, if the primer had been too large and had generated sufficient pressure and flame to ignite all grains of propellant simultaneously, too high pressure may have developed too early and rapidly.

Thus, the optimum relationship was developed between the propellant pressure-time curve and the primer fuze and type and did not require the use of flash tubes.

IGNITION SYSTEM CANDIDATES

1. XM-115 primer (Frankford Arsenal X10543585) is currently used in the 20mm M187E1 cartridge case fired in the Hispano-Suiza 820 gun. (M139 is the Army designation of this gun.)

2. M36A1B1 primer is presently used in all mechanically-ignited ammunition such as the M90-series 20mm. This primer would have been inserted in a primer pocket similar to that in the 20mm Navy Mk 5 case.

3. FA-1054281 flash tube would have been used in conjunction with the M36A1B1 primer. It is presently used in the 30mm XM193 cartridge case, fired in the U. S. Army 30mm XM140 gun carried aboard helicopters.

4. Percussion primer assembly (Type T) is a threaded, flash-tube assembly which contains standard primer M36 and is currently used in the 27.5mm cartridge case being developed by Amron for Aerojet for another program.

5. M52A3B1 primer is presently used in all electrically ignited ammunition such as the M50-series and Mk 100-series 20mm. This primer would have been inserted in a primer pocket similar to that in the 20mm Navy Mk 5 case.

PRIMERS

The proper primer, primer pocket, flash hole and propellant were selected to constitute the desired ignition train.

These experimental XM-115 primers used in the first firing tests had about .003 in. interference fit in the primer pockets.

This was found to be almost ideal from previous studies. Subsequent studies of 100 primer and primer pocket dimensions revealed:

1. Interference on diametric fit of .0008 in. to .0056 in.
2. Primer ellipticity of .0009 in. to .0034 in.
3. Average primer diameter of .3748 in. to .3781 in.
4. Primer height of .2655 in. to .2703 in.
5. Pocket diameter of .372 in. to .373 in.
6. Pocket depth of .264 in. to .266 in.
7. Pocket positive taper of .001 in.

In actual use, the usual primer insertion device exerted insufficient pressure to seat the primers properly. A new priming device was constructed to alleviate this difficulty. An arbor press was used to seat the primers .003 in. ±.001 in. below the base of the case. As was seen by examining inserted primers, some of the primers were not seated squarely in the primer pockets due to irregularities in the lip of the primer cup.

Examination of unused XM-115 primers revealed that some anvils are not seated squarely in the primer cup. Therefore, a plane across the anvil legs would not be parallel to the plane of the primer cup bottom. This helps to account for the lack of solid 360° contact between assembled primers and their primer pocket bottom as well as the presence of cocked primers (See Figure 12).

The hardness of the primer cups was investigated, and the following summary resulted:

1. <u>Metallurgical Evaluation of XM-115 Primers</u>

The microexamination of the subject product indicated:

a. The anvil and the cup are produced from copper alloy 260, cartridge brass.

b. The Diamond Pyramid Hardness (D.P.H.) of 182(Rockwell B-RB-89) for the anvil would indicate a finished temper of extra hard.

c. The cup hardness was D.P.H. 190 (RB-91) at the sidewall and D.P.H. 100 - 110 (RB-55 to 62) at the base.

2. <u>Conclusion</u>

The XM-115 primer specimens are manufactured from the proper copper alloy. The anvil is slightly harder than the

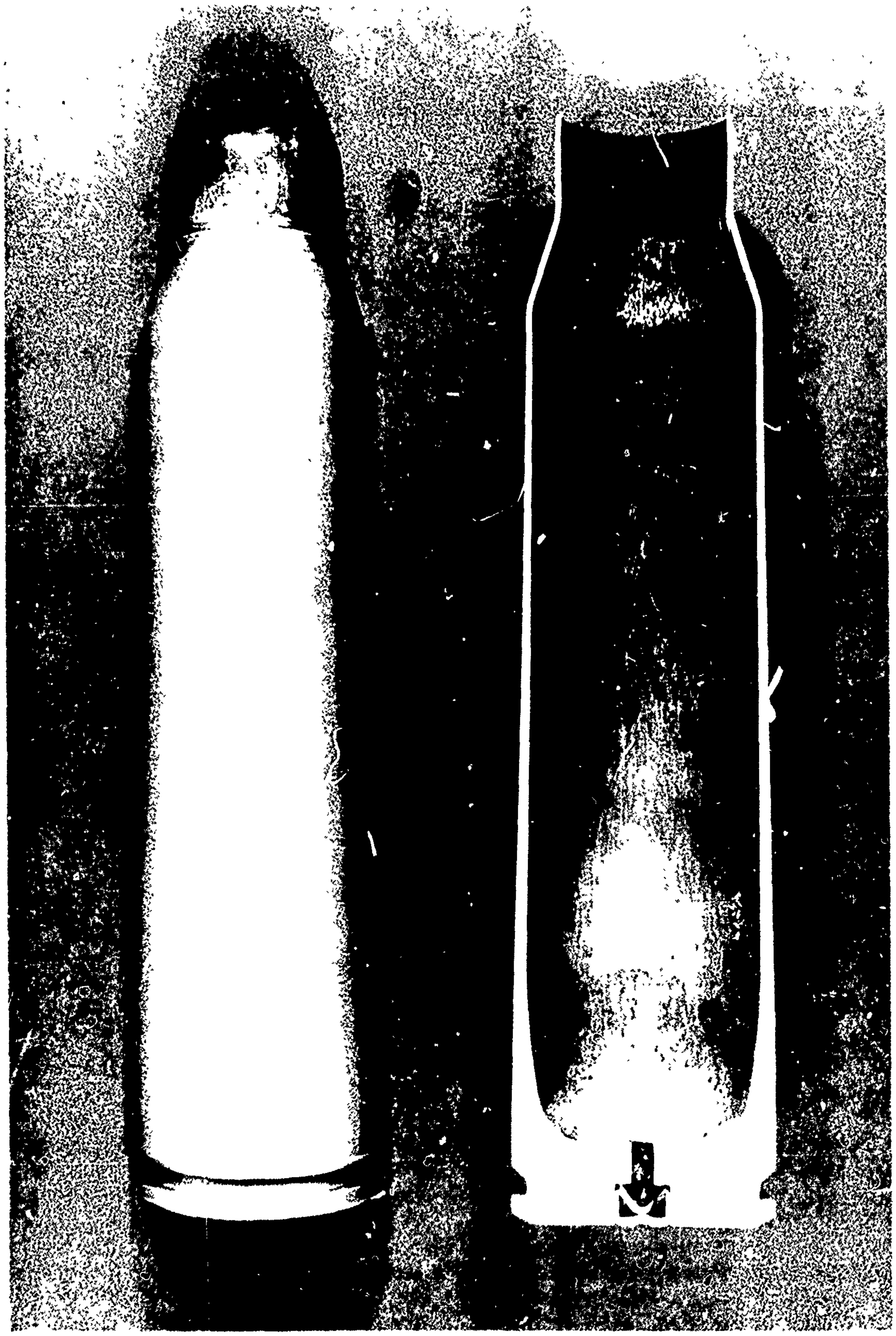


Figure 12 Cross Section of Case with Inserted Primer

specification hardness of half hard and the cup is as-cold-worked from annealed strip stock. The high hardness of the anvil should not affect the intended function of the product, but the high hardness of the cup sidewall will result in a yield strength of 65,000 psi as opposed to 22,000 psi for an annealed cup.

During previous work with 20mm aluminum cartridge cases, the possibility of gas leaks at the primer pocket became apparent. It has been noted that high yield strength in the sidewall of a primer inserted into an aluminum cartridge case will act as a contributing factor for primer gas leaks, because the high yield strength will not allow proper sealing between the cup sidewall and the primer cavity wall.

Primer leaks were nonexistent in all instances where the sidewalls of the primer pockets were smooth. There is evidence, though, that the work-hardened sidewalls of the primers, in conjunction with the unfinished lip of the primer cups, can produce longitudinal scratches in the pocket wall. These can, in turn, initiate primer leaks. This condition can be readily identified by the observance of bubbles forming following application of the primer sealant.

At such time that future assembly of these primers into aluminum cases becomes necessary on a production basis, it is recommended that the primer cup lip be trimmed, followed by annealing of the work-hardened wall of the primer cup.

SECTION V

SURFACE FINISH

GENERAL

One of the major parts of the engineering and design study of the 30mm aluminum cartridge case contract is surface finish development. The desired characteristics of a surface finish for aluminum cartridge cases have been projected as follows:

1. Maintain the structural integrity of the case.

2. Resist surface oxidation and retain initial appearance.

3. Retain good resistance to stress corrosion cracking.

4. Provide sufficient anti-seize properties, both initially and after prolonged field storage, to enable satisfactory functioning of the cartridges under rapid fire conditions.

5. Be practical and economical for mass production.

As a result, the total finishing system must consider cleaning and preparing the surface, applying a protective coating, and applying an anti-seize coating.

Amron and Alcoa have concurrently, but separately, developed surface finishing systems for application to the 30mm aluminum cartridge case.

ALCOA RESEARCH LABORATORIES INVESTIGATIONS

RECOMMENDED FINISHING TREATMENTS FOR X7475-T73 ALLOY

Extensive data have been accumulated in evaluating finishing treatments applied to X7475-T73 alloy. These data include accelerated corrosion test results and physical measurements such as kinetic coefficient of friction, abrasion tests, reverse-impact, and diamond scratch hardness determinations. The data were utilized to find coating systems having properties required for cartridge case application, which at the same time can be readily applied. Using these criteria for screening candidate finishing systems, coatings have been selected for application to X7475-T73 alloy.

The recommended cleaning processes required three different treatments:

1. An inhibited or non-etching alkaline cleaner to remove fingerprints, oil and shop soil.

2. An acid etch in a solution containing 10% by volume of 48% hydrofluoric acid and 10% by volume of 70% nitric acid at room temperature.

3. A desmutting treatment at room temperature in 1:1 nitric acid to remove the light smut film which forms on the surface of the work during acid etching.

The first recommended finishing treatment is a thin anodic oxide coating applied in sulfuric acid at 70°F for 10 minutes. The most corrosion-resistant coating evaluated in this work was either a dichromate-sealed or a dual nickel acetate-sodium dichromate-sealed Alumilite coating. The first suggested sealing operation is carried out by immersing for 10 minutes in sodium dichromate at 185°F. The latter sealing technique requires 5 minute immersion in a boiling solution containing nickel acetate, followed by a ten minute immersion in sodium dichromate at 185°F. Further corrosion protection and especially a lower kinetic coefficient of friction can be obtained by subsequently applying a wax emulsion coating (deposited from a boiling water solution). Optimum results were obtained with the dichromate-sealed Alumilite coating with a thin film of McLube 1700 fluoro-carbon lubricant (McGee Chemical Co.). The boiling wax and the fluoro-carbon lubricant treatments can be applied to unsealed Alumilite coatings, but neither is as corrosion resistant as that sealed in dichromate. A boiling water-sealed anodic coating also has adequate corrosion resistance and the application of McLube 1700 will improve the anti-stick characteristics. Other sealing combinations can probably be incorporated in the anodizing approach.

A second system employs an epoxy phenolic coating such as Varcum 5417 (Reichhold Chemical, Inc.). It is not only corrosion-resistant but also has a low kinetic coefficient of friction when applied to X7475-T73 alloy. If a still lower coefficient is required, an internal lubricant, such as K-39 (Midland Chemical Co.) can be added to the formulation before spraying, without detrimentally affecting other coating properties. The Iridite 14-2 conversion coating substrate did not significantly enhance the adhesion of the subsequently applied Varcum coating, when compared to the adhesion of an as-cleaned-only surface; although it would provide a further safety factor.

The third recommended treatment, and probably the easiest to apply, is the chromium chromate-McLube 1700 tandem coating. A minimum conversion coating weight of 23 mg/ft^2 is recommended, although care should be exercised to avoid heavy coating weights which produce powder or flakey residues. Typical commercial formulations which give similar results include Iridite 14-2, Alodine 1200 and Bonderite 721. This tandem coating is not quite as resistant to corrosion as the dichromate-sealed anodic oxide or the organic coatings mentioned above, although it does have excellent friction characteristics.

It should be understood that these recommendations are based on work conducted on X7475-T73 alloy sheet. Although these recommended finishing treatments have been applied to 30mm aluminum cartridge cases, the test data on such specimens are incomplete. The selection of a final finishing treatment will depend on the application and performance characteristics on actual cases and on the relative economics for equivalent performance.

CONCLUSIONS

Based on test results compiled in this report, the following conclusions can be drawn:

1. A solution containing 10% by volume hydrofluoric acid (48%) and 10% by volume nitric acid (70%) can be effectively used to clean X7475-T73 alloy.

2. McLube 1700 fluoro-carbon lubricant provides significant corrosion protection to all types of substrates when applied as a continuous thin film.

3. The most corrosion resistant coatings evaluated were a dichromate-sealed anodic oxide coating (0.00007 in. or 0.00015 in.) or a dual nickel acetate-sodium dichromate-sealed anodic oxide coating, with a subsequently applied thin film of McLube 1700 fluoro-carbon lubricant in either case. These coatings showed no trace of corrosion even after 24 hours in the corrosive CASS test.

4. The easiest and least time-consuming coating to apply is a thin (23 mg/ft^2) chromium chromate conversion coating with a thin film of McLube 1700. It is felt that this coating has enough corrosion resistance for cartridge case application.

5. The epoxy phenolic coating, Varcum 5417, is both corrosion-resistant and has a low coefficient of friction. It can be applied to an as-cleaned-only substrate without experiencing adhesion difficulties.

6. It is better to employ a sealing treatment on an anodized finish prior to the application of a lubricant film, rather than rely on the lubricating film to fulfill both functions. If it is necessary to seal and lubricate with a single treatment, the fluoro-carbon McLube 1700 is the most promising.

7. In stress-corrosion testing (6% boiling NaCl solution) X7475 alloy cartridge cases, the T73 tempered cases showed excellent resistance to stress-corrosion cracking, regardless of whether they were crimped or whether or not the mouths were annealed.

8. It is believed that the aging cycle for X7475-T73 alloy cartridge cases could be shortened by substituting a heat treatment of 3 hours at 250° for a treatment of 6 hours at 225°F, without substantially affecting the tensile properties or stress-corrosion resistance.

9. All of the recommended coatings passed the formability tests (conical mandrel and reverse impact) on X7475-T73 alloy sheet. Moreover, the dichromate-sealed Alumilite coating had the highest diamond scratch and abrasion-resistance of all tested samples.

AMRON INVESTIGATION

RECOMMENDED COATINGS FOR X7475-T73 30mm CARTRIDGE CASES

The MEPOC coating is a modified epoxy phenolic organic coating, that has been successfully applied to steel and other aluminum products over various surface preparations.

Another coating, 26A (Sandstrom Products Co.), is commercially available from at least two sources and is currently being applied to a large number of military and commercial i+ --s, including ammunition links, aircraft cables, weapon ba els, mmunition boxes and moving gun components.

RIM SHEARS AND OTHER EXTRACTION DIFFICULTIES

Although these were encountered in earlier programs, they were not a serious current problem. The general approach to elimination of this difficulty was to select a material and a case design which would insure sufficient recovery to eliminate case sticking, to develop a finish which would facilitate extraction, and to exercise due caution in the design of the rim. The effect of a hot weapon chamber was not ignored. The only extraction difficulty was with one case that had been exposed to 81,000 psi piezo pressure.

CORROSION, STRESS CORROSION CRACKING AND DETERIORATION OF FINISH

There was no evidence or inter granular corrosion, galvanic corrosion, stress corrosion cracking, or deterioration of finish with the final alloy, temper, or surface finishes. The stress corrosion test of the case with crimped projectile, however, was not completed as fully as desirable. At this time, however, no failures in this category have occurred, because of the satisfactory combinations of alloy, temper, and finish that have been developed. The 26A has completely eliminated the galling and tearing of aluminum during projectile decrimping and the propellant hot gas erosion in the primer and neck areas. It is also anticipated that automatic weapon firing will present no difficulties with its more rigorous stop and start conditions which produce a hot chamber and possible coating degradation with resultant case seizing.

The 26A meets or exceeds the environmental and functional requirements for many military items and requirements of MIL-L-46009 and RIA PD-703 as an air drying, corrosion inhibiting, dry film lubricant.

COST ANALYSIS

A cost analysis of the recommended finishing treatments is compiled below for comparative purposes. All systems listed have satisfactorily passed all required tests up to and including firing in a Mann Barrel.

Considered in this analysis were:

1. Surface preparation
2. Substrate
3. Coating
4. Additional surface treatment
5. Top coat
6. Labor
7. Material
8. Equipment

The estimates are based on a production rate (30mm aluminum cartridge cases) of 500,000 per month. At this rate and assuming 22 working days of two shifts, each, per month, an average of 24 cases per minute must be processed. Obviously, considerable effort will be required in designing handling equipment for this volume of production, and the ultimate costs will depend greatly on how well that job is done.

In Table III the coating systems and costs were combined on the same comparative basis. All systems require the same careful surface preparation of inhibited alkaline cleaning to remove fabrication residues, hydrofluoric-nitric acid etching to remove the thermal film and activate the surface, and nitric acid desmutting.

In this process, a unit cost of 1 for cleaning and 2 for etching is assumed. Whether this unit represents 1/4 cent per case, 1/10 cent per case, or something else, will depend on the effectiveness of the processing equipment design.

On the same scale, anodizing and sealing (0.00015 in. coating with dichromate seal) might be 8 units, chemical conversion coating 2 units, and organic coating 5 units.

TABLE III. COATING SYSTEMS AND COSTS ON A COMPARATIVE BASIS

	ALCOA SYSTEMS			AMRON SYSTEMS		
	1	2	3	4	5	6
Cleaning	I&O*1**	I&O 1	I&O 1	I&O 1	I&O 1	I&O 1
Etching	I&O 1	I&O 1	I&O 1	I&O 1	I&O 1	I&O 1
Desmutting	I&O 1	I&O 1	I&O 1	I&O 1	I&O 1	I&O 1
Anodic Oxide	I&O 7					
Chromium Chromate		I&O 2	I&O 2	I&O 2	I&O 2	
Dichromate Seal	I&O 1					
Fluoro-carbon	O 5		O 5			
Epoxy Phenolic		O 5				
MEPOC				O 5		
Epoxy-MoS_2					O 6	O 7
Total cost Units	16	10	10	10	11	10
Per Case Cost (¢)	4.0	2.5	2.5	2.5	2.75	2.5

* Applied to Interior (I) and Outer (O) surfaces.

** Cost unit of each operation

Conversion of these relative values to actual cents per case is subject to wide variation. It is believed, however, that even with low efficiency production facilities, per case coating costs of 4 cents, 2.75 cents and 2.5 cents, respectively, would not be exceeded.

COATING SYSTEMS

1. Alumilite (anodic oxide - .00015 in.) by 15% H_2SO_4, 70°F, 12 asf (amps/sq.ft.) for 10 minutes, then 10 minutes at 185°F in 5% sodium dichromate, plus McLube 1700 (fluoro-carbon) aerosol lubricant.

2. Iridite 14-2 (chromium chromate conversion coating - 23 mg/ft^2) plus Varcum 5417 (epoxy at .0002 in.) cured at 350 F for 30 minutes.

3. Iridite 14-2 (chromium chromate conversion coating - 23 mg/ft^2) plus McLube 1700 (fluoro-carbon) aerosol lubricant (less than .0001 in.).

4. Alodine 1200 (chromium chromate conversion coating) plus MEPOC (Modified epoxy phenolic organic coating).

5. Alodine 1200 (chromium chromate conversion coating) plus 26A (modified molybdenum disulfide-epoxy at .0004 - .0006 in.) air-dried or dried at 290 ± 10^{o}F for one minute.

6. Fresh, scrupulously clean bare aluminum plus 26A (modified molybdenum disulfide-epoxy at .0004 - .0006 in.) air-dried or dried at 290 ± 10^{o}F for one minute.

SECTION VI

FIRING MECHANISM

GENERAL

The Mann barrel, breech block, and yoke were manufactured by the Mathewson Tool Company, Orange, Connecticut. This vendor was selected because of the total cost of the items and the ability of the vendor to deliver these vital components. The firing mechanism, as shown in Figure 13, is mounted in the Amron ballistic test facility and has the capability to measure copper crusher and piezo quartz pressures.

BARREL SPECIFICATIONS

Material	4150 Steel
Heat treated to	Rockwell "C" 34-36
Length of barrel	95.00 ± .150 in.
Rifling data (from breech):	
Chamber	0 to 7.175 in.
Zero twist	7.175 to 10.175 in.
Gain twist	10.175 to 79.425 in.
Constant twist	79.425 to 95.000 in.
Exit angle	8° - 58 minutes
Number of grooves	20
Groove depth	.0195 ± .001 in.
Groove width	.110 ± .004 in.
Land diameter	1.1835 ± .001 in.

PROBLEM RESOLUTION

Some difficulty was initially encountered in obtaining the proper firing pin energy to ignite the primer. With the insertion of a heavy spring on the firing pin, the numerous misfires encountered during the first tests were eliminated.

GOVERNMENT-FURNISHED EQUIPMENT (BARRELS)

The six gain twist test barrels (FF6357), supplied to Amron as government furnished equipment, were not used because rechambering for the RE-5-102 cartridge case would not leave sufficient material for safe test firing. Also, these barrels are approximately 50 in. long and are unsatisfactory for this program. The Air Force suggestion that two barrels be joined together to

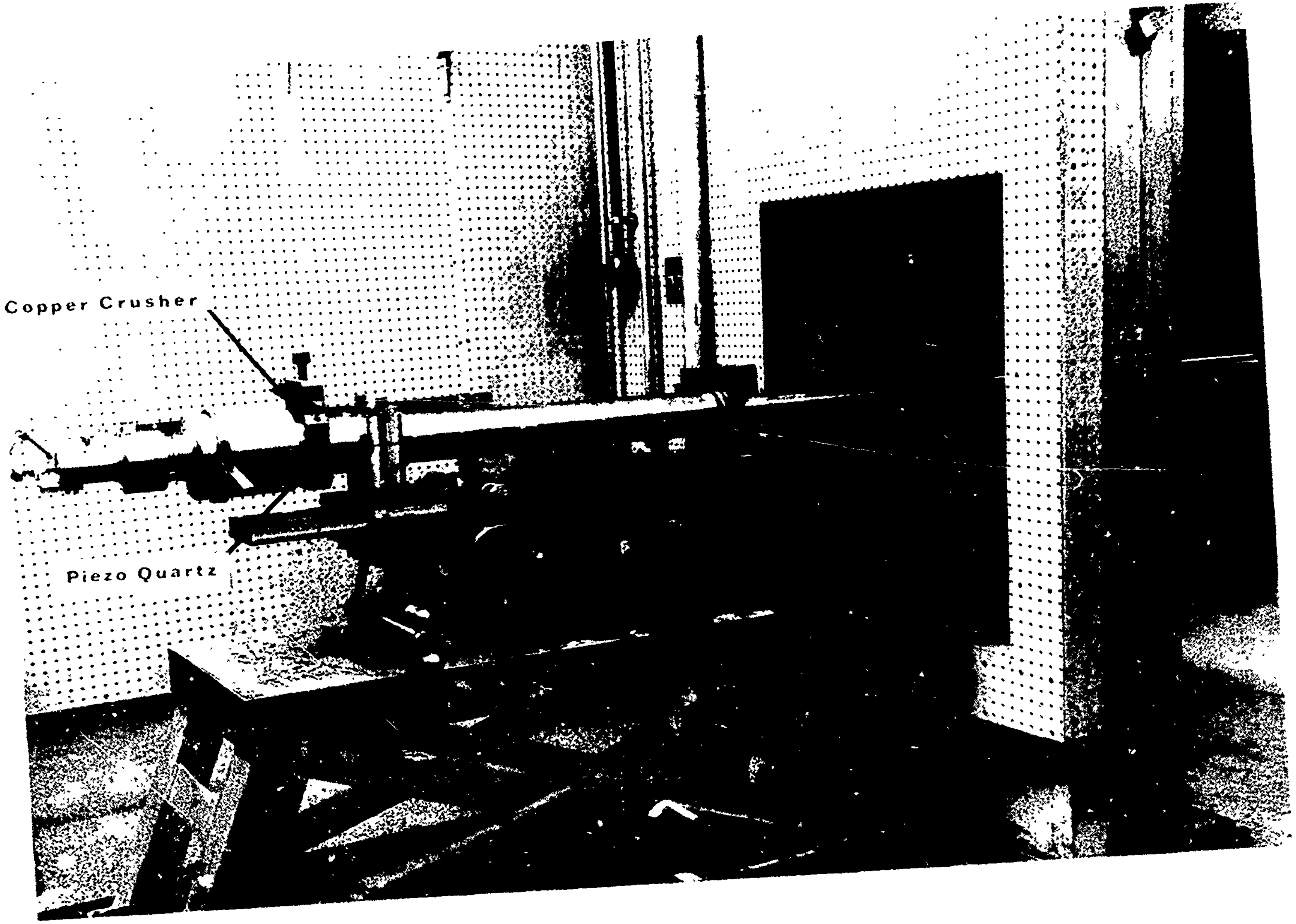


Figure 13. AX Firing Mechanism

achieve the desired 95 in. length was rejected by the Program Manager because a projectile would increase its rotational velocity until it reaches the second barrel where there would be a reduction in the rotational velocity due to the reversing of the gain twist.

SECTION VII

TEST FIRING

GENERAL

This section describes the test firing performed. Tables IV through VIII show the results of the firings under various comparative conditions with 5000-grain projectiles.

1. Temperature Preconditioning

The effects produced by varying the preconditioning temperature of the assembled round are tabulated below. There is a definite increase in both velocities and pressures as the preconditioning temperatures change from - 65°F to 70°F to 165°F.

TABLE IV - Temperature Preconditioning

	Number Readings	Muzzle Velocity[1]	Number Readings	Pressure (Copper)
Cold	13	3420 fps	13	36,298 psi
Ambient	134	3565	143	43,050
Hot	13	3601	13	48,500

[1]Muzzle Velocity (approximate) = Velocity at 100 feet + 100

2. Hardness

The effects produced by two conditions of mouth hardness on pressure and velocity proved to be indistinguishable as illustrated below. Once again, all conditions remained constant except mouth hardness.

TABLE V - Mouth Hardness

Condition	No Fired	Pressure (Copper) psi	Pressure (Copper) %Spread	Muzzle Velocity[1] Ft/sec.	Muzzle Velocity[1] %Spread
Annealed	10	43,715	9.49	3587	1.06
T-73	29	43,292	8.89	3585	1.89

[1]Muzzle Velocity (approximate) = Velocity at 100 feet + 100

3. Copper Versus Kistler Pressures

Simultaneous measurements of copper crusher cylinder and Kistler Piezo-electric peak pressures were made. The results of ambient temperature firings consistently show Kistler to be 1.25 times the copper pressures. Average results follow:

TABLE VI - Copper vs. Kistler Pressures				
Temperature	No. of Samples	Kistler	Copper	Kistler/Copper Ratio
Cold	3	43,167	36,140	1.194
Ambient	41	53,439	42,916	1.245
Hot	1	60,400	48,500	1.247

4. Coatings

The coatings were compared for possible effects on pressure and velocity. All other conditions of projectile and propellant weights, temperature, crimping, and case hardness remained constant. There was no significant difference between the various groups.

TABLE VII - Coatings of Fired Cases		Pressure (Copper)		Muzzle Velocity[1]	
Coatings Plus No. Fired		psi	%Spread	ft/sec.	%Spread
Anodized[2]	C[3]	44.308	22.00	3522	2.49
Alumilite-McLube 1700	5	42,304	5.15	3564	1.26
Iridite 14-2-McLube 1700	5	41,860	6.09	3560	.45
Alodine-MEPOC	29	43,292	8.89	3585	1.89
Bare Aluminum-26A	5	43,840	4.11	3580	.62

[1]Muzzle Velocity (Approx.) = Velocity at 100 feet + 100

[2]Loaded and Fired with 2300 grains of 1379C (others loaded with 2350 grains).

[3]Pressure-average of 12 results; velocity-average of 6 results.

5. Current System for Interior Ballistics

Barrel Length: Total - 95 in. Projectile Travel - 87.825 in.

Projectile Weight: 5,000 grains.

Propellant: C.I.L. 1379C, Bulk Density - 0.966 g/ml (244.3 gr/in.^{3}).

Case Volume: Full - 11.97 in.^{3}; With Dummy Projectile - 11.4 in.^{3}.

Propellant Weight: Maximum Possible (11.0 in.^{3}) - 2687 gr., Actual - 2300 gr. (9.41 in.^{3}), 2325 gr. (9.51 in.^{3}), and 2350 gr. (9.62 in.^{3}).

6. Summary of Results

The summation of Ballistic Results Table 8 shows the total number of cases fired under the various conditions.

TABLE VIII - Summation of Ballistic Results

Conditions	No. Readings	Muzzle* Velocity	No. Readings	Copper Pressure	No. Read-ings	Kistler Pressure
Dummy Projectile						
Room Temperature						
2300 gr 1379C	38	3550 fps	40	43,477psi		
2315 gr 1379C	1	3523	1	41,320		
2325 gr 1379C	17	3539	17	42,382		
2350 gr 1379C	78	3579	85	43,003	41	53,427psi
Cold Temperature						
2300 gr 1379C	10	3418	10	36,345		
2300 gr 1379C	3	3429	3	36,140	3	43,167
Hot Temperature						
2300 gr 1379C	12	3593	12	45,450		
2350 gr 1379C	1	3696	1	48,500	1	60,500
Room Temperature						
1900 gr WC870	1	3444		56,800		
2050 gr WC880	2	3497		57,550		
1800 gr 1379A	1	--		35,600		
2000 gr 1379A	1	--		45,650		
2225 gr 1379A	2	3696		58,600		
2250 gr 1379A	3	3758		62,044		
2300 gr 1379A	1	--		64,380		

*Approximate muzzle velocities were obtained by adding the average distance of velocity determination to the velocity obtained at that distance (Ex. V_{100} of 3450 fps plus 100 equals 3550 fps).

7. Time Pressure Curve

The Time Pressure Curve (Figure14) is a typical curve that results when piezo quartz pressure in psi is plotted versus time in milliseconds. The significant aspects of these curves encountered during this developmental program are:

1. 0 to 1 ms - primer ignition
2. 1 to 1.4 ms - primer pressure and start of propellant ignition

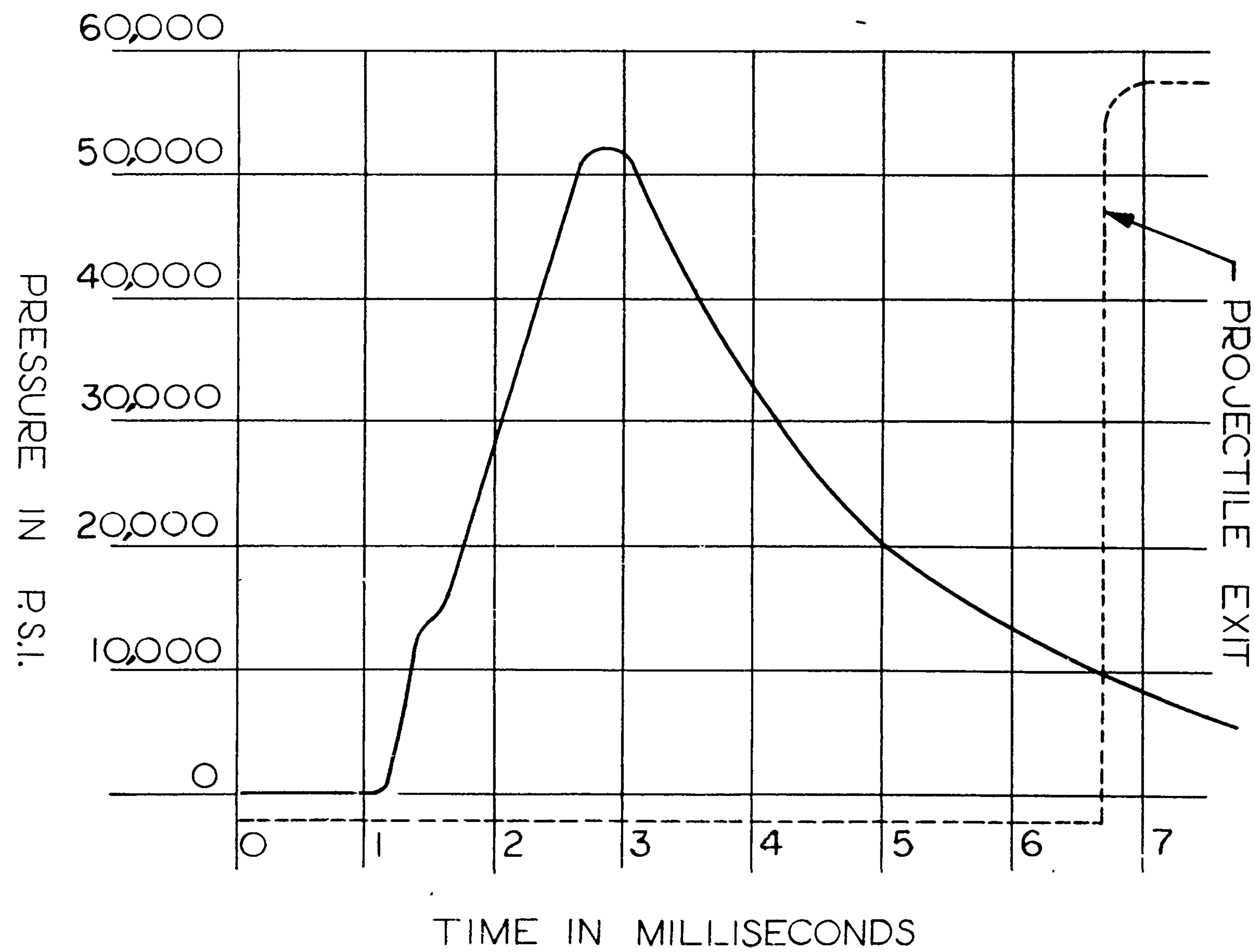


Figure 14 Time Pressure Curve

3. 1.4 to 1.6 ms - primer pressure decays, propellant pressure rises, and projectile movement begins

4. 1.6 to 2.7 ms - propellant pressure rises

5. 2.7 to 3.0 ms - propellant burning ceases

6. 3.0 to 6.7 ms - propellant pressure decays

7. 6.7 ms - projectile exits barrel muzzle

STUDIES OF METAL EROSION DURING TEST FIRING

The following two reports were made after some incidences of propellant gas leaks out of the cartridge case. It should be realized that these were caused by erosion of the metal by the hot propellant gas and not by failure of the metal in the case.

1. <u>Study of Hole in Neck Area</u>

T73 temper with MEPOC coating (not mouth annealed).

a. Holed Case

(1) Neck-shoulder hole (Figure 15)

(a) Only the tadpole's tail eroded through to the outside; the "body" was physically torn loose due to fusion in "tail" area of the case to the chamber.

(b) Not due to crimping of projectile; apparently due to interior metal split in "tail" area with lamination in "body" area of case interior.

(c) Peripherally around the interior of the case, uneroded pits indicated metal weaknesses, or "dirt" during forming which came off during cleaning.

(2) Dark streaks from crimp to extractor groove on exterior.

(a) All streaks are inconsistently diagonal with pitted heads toward the case base.

(b) The streaks do not go through to the inside and are still covered with MEPOC.

(c) It appears that "dirt" was present during final forming of the case which came off during cleaning in preparation for coating.

b. All other nine cases in this series exhibited pits, with or without streaks, in the interior and exterior to a lesser extent, but no hole occurred.

CONCLUSIONS:

1. The clear MEPOC makes case defects much more visible than the Alcoa coatings.

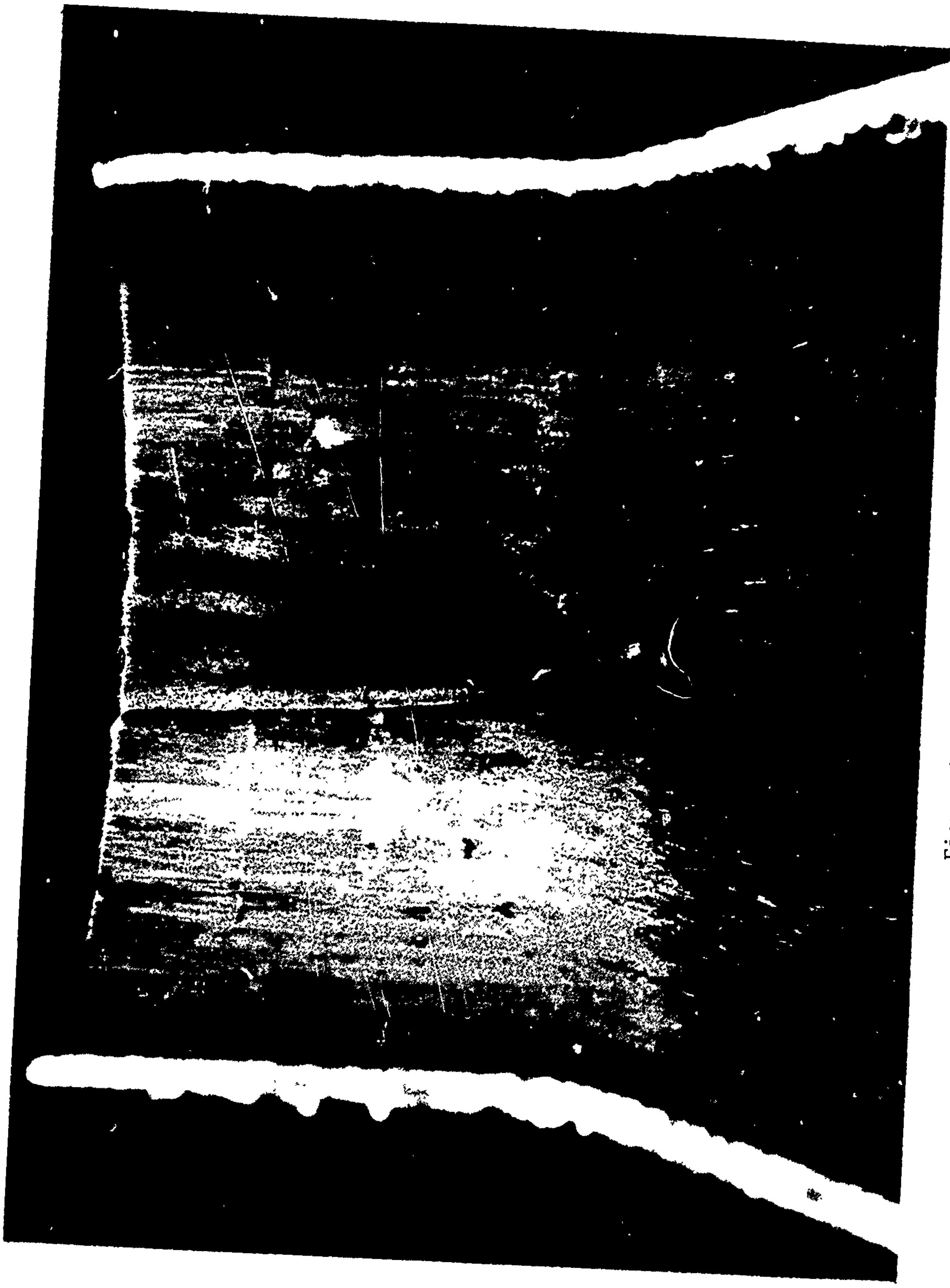


Figure 15. Hole in Case Neck

2. The dark streaks on the outside probably form as a result of turbulence, created by the pits, during the spraying of the cases. This produces a variation in coating texture which is accented by the heat of the curing oven.

3. Pits form due to "dirt" on the case during the final forming operations which came off during the cleaning of the case in preparation for the coating process.

4. An area of metal weakness in the neck-shoulder area allowed hot propellant gases to jet through and fuze a spot in the case neck to the chamber wall which physically tore loose from the case when removed from the chamber.

5. This area of metal weakness was likely due to foreign material inclusion in the metal incorporated during the final draws.

2. Study of Primer Leak

Components (worse conditions)

a. XM-115 Primers

(1) Unequal length of primer cup sides.

(2) Unfinished primer cup lip (rough).

(3) High hardness of primer cup sides(extra hard D.P.H. 190-Rockwell B-91) with yield strength of 65,000 psi.

(4) Low hardness of primer cup bottom (half hard D.P.H. 100 to 110-Rockwell B-55 to 62).

(5) Voids in exterior side wall of primer cup.

(6) Longitudinal forming-scratches in exterior side wall of primer cup.

(7) Elliptical circumference (.0009 to .0034 in.).

b. Primer Pocket

(1) Tapered side wall (.0005 to .0015 in.).

(2) Low hardness of side wall (74-76R30T).

(3) Circumferential gaging marks in base metal of side wall.

(4) Voids in side wall and bottom.

(5) Alodine-coated only (chromium chromate conversion coating with no top-coat).

(6) Longitudinal scratches through Alodine into aluminum in side wall by paint spray conveyor spindle.

c. Assembly

(1) Dimensions

(a) Interference on average diameter (.0008 to .0056 in.).

(b) Crush-up on length (.0015 to .0163 in.).

(c) Seating depth below flush (.002 to .004 in.).

(2) Actions During Priming

(a) Arbor press used for seating.

(b) Rough, hard lip of primer cup machines side wall of pocket through coating into base metal (longitudinal gouges and some metal particles torn loose).

(c) Hard primer cup side wall assumes taper of primer pocket side wall (.0005 to .0015 in.).

(d) Primer sealant used.

(e) No primer staking used.

(f) Pre-conditioned to 165°F before firing.

d. Actions During Firing

(1) Firing pin impacts (soft primer cup indents - crushing and igniting primer mix against anvil).

(2) Primer mix detonates (force loosens and backs out primer against bolt face - .003 to .005 in. protrusion out of pocket).

(3) Flash of primer mix ignites propellant (hot gas of burning propellant then comes back into primer pocket through flash hole - piezo quartz at 60,500 psi).

(4) Hot gases rush through annular arc between the hard primer wall and primer pocket on the loosest side where the primer cup lip is farthest off the pocket bottom and between anvil legs.

(5) Erosion of the primer and pocket wall occurs along longitudinal scratches and in areas of turbulent gas wash due to pits and voids (aerodynamic friction raises the eroding gas temperature from the melting point of aluminum to near the boiling points of both aluminum and cartridge brass).

(6) The primer wall erodes through from the outside to the inside (see Figure 16).

(7) The hot propellant gas follows the path of least resistance across, eroding the bolt face and cartridge case head protruding beyond the chamber.

Figure 16 Primer Wall Erosion

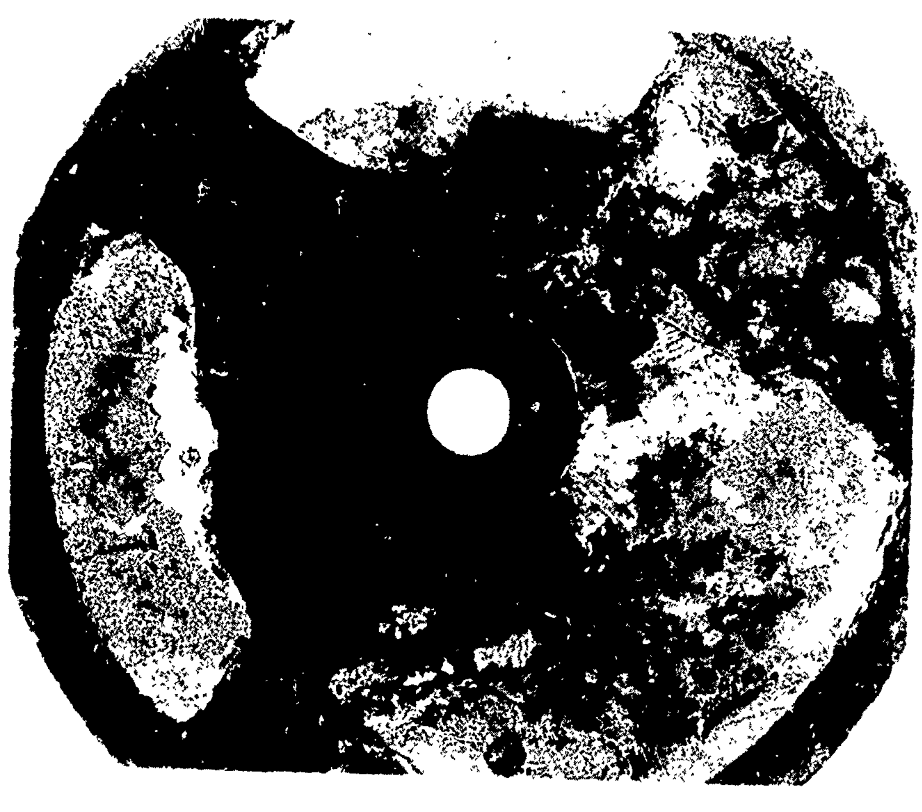


Figure 17 Cartridge Case Erosion

(8) Only very rarely is burning noted (as evidenced by oxide coating formation).

(9) No damage whatever is done to the flash hole or case interior walls (see Figure 17).

MISFIRES

There were four instances during this project in which the primer ignited but the propellant did not. There was one that occurred at -65^{o}F and three at 70^{o}F. All occurred during the last week of the contract. Thus, there was insufficient time to experiment and document the reasons for these malfunctions. Some of the possible contributory causes are:

1. Movement of primer by firing pin impact.

2. Light firing pin impact did not give near-simultaneous ignition of primer mix.

3. Temperature differential between 70^{o}F and -65^{o}F, coupled with differential in thermal expansion between the brass of the primer, the aluminum of the primer pocket, and the steel of the projectile, caused the case to "breathe" and draw moisture into the propellant or primer mix.

4. Cracked primer mix pellet due to inadequate reconsolidation during primer insertion.

5. Underloaded primers.

6. Propellant away from primer at moment of primer ignition. This was done on purpose to three rounds at 70^{o}F. to study the effects produced by excess case volume. Two misfires resulted.

SECTION VIII

CONCLUSIONS

GENERAL

The Amron designed cartridge case has been satisfactorily manufactured and withstood all tests performed under this contract.

CASE DESIGN

1. The case designed is capable of withstanding the pressure to achieve 3500 ft per second muzzle velocity with a 5000-grain projectile.

2. The overall length of the cartridge case can be reduced the equivalent of 0.6 cu in. interior volume.

MATERIAL

1. The case material X7475-T73 aluminum alloy is feasible for further development in an automatic weapon system providing all surface irregularities are eliminated to prevent turbulence of hot propellant gases.

2. Raw material should be purchased as plate at proper thickness of alloy X7475 - OE4 temper, fine grain size and of cartridge case quality.

3. Chemical composition limits: X7475-T73:

Silicon	Iron	Copper	Manganese	Magnesium
0.10% max.	0.12% max.	1.2 - 1.9%	0.06% max.	1.9 - 2.6%

Chromium	Zinc	Titanium	Others	Aluminum
0.18 - 0.25%	5.1 - 6.2%	0.06% max.	Each 0.05% Total 0.15%	Remainder

4. Minimum hardness measured at the internal portions of the finished cartridge case X7475-T73 head section and throughout the wall section shall be $R_{30}T$ 72 minimum. The mechanical properties of tensile and percent elongation measured at a point 1.5 to 2.0 inches from the face of the head section should be:

Ultimate psi minimum	Yield psi (.2% offset) minimum	% Elongation (1 in. gage) minimum
70,000	60,000	8

PROPELLANT

1. The propellant to be used is 1379C from Canadian Industries Limited per Table II. A total of 2350 grains of this propellant is nominally required to drive a 5000-grain projectile to

muzzle velocities in excess of 3500 feet per second; 10.1 cubic inches behind the projectile is to be provided for adjustment of the required propellant with varying conditions.

PRIMER

1. The primer to be used is the production model of the Frankford Arsenal XM-115 percussion primer. This primer is to be loaded to its full capacity with approximately 4 grains of primer composition FA 956. The lip of the primer cup shall be made smooth and regular. The primer cup itself shall be annealed before loading in order to relieve the work-hardening of the cup wall.

ASSEMBLY

1. The primer shall be inserted .002 - .006 in. below flush in the primer pocket, sealed and water-proofed with primer sealer MIL-L-10287 sealing lacquer, and staked in the primer pocket through 360°.

The base of the projectile shall be coated with waterproofing of Ordnance Type III Sealing Compound per MIL-A-82484, inserted into the cartridge case, and have applied a 360° hydraulic crimp.

SURFACE FINISH

1. It is believed that the epoxy-phenolic copolymer coatings over a chromate treatment of the aluminum in an automatic rapid-fire gun system provide all required properties. However, should additional lubricity or higher temperature resistance be required due to the stop and start conditions of a rapid-fire system, air drying corrosion inhibiting dry film lubricant per MIL-L-46009 should be used over fresh clean aluminum

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13 ABSTRACT

This report describes the design, development, and testing of a 30mm aluminum cartridge case for the Air Force 30mm AX gun system. The program proves that a 30mm cartridge case is feasible and can be manufactured using the Aluminum Company of America X7475 material. Also, the Amron-designed cartridge case can be satisfactorily fired to the parameters set forth in the contract covering this program. This effort consists of an in-depth study of surface finishes that can be economically applied to aluminum. This report also describes the successful application of the XM-115 percussion primer (FA X10542585), developed by the U. S. Army at Frankford Arsenal.

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